CORRECTIONS

Technical Bulletin No. 274, United States Department of Agriculture, Hot Water as an Insecticide for the Japanese Beetle and its Effect on the Roots of Nursery Plants. by Walter E. Fleming and Francis E. Baker.

Page 6. In the sixth line from the bottom, Figure 6 should be changed to Figure 5.

Page 37. In the list of species of Iris, the line reading:

pseudacorus... Yellowflag iris... Retarded.

should be changed to read:

pseudacorus... Yellowflag iris... Do.

TECHNICAL BULLETIN NO. 274 JANUARY, 1932

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

HOT WATER AS AN INSECTICIDE FOR THE JAPANESE BEETLE IN SOIL AND ITS EFFECT ON THE ROOTS OF NURSERY PLANTS

By WALTER E. FLEMING, *Entomologist*, and FRANCIS E. BAKER, *Assistant Entomologist, Division of Japanese and Asiatic Beetle Research, Bureau of Entomology*

INTRODUCTION

One of the important problems in the control of the Japanese beetle, *Popillia japonica* Newman, is the development of methods for treating the subterranean portions of evergreen, deciduous, and herbaceous plants to destroy all stages of this insect. The shipment of these plants with soil to points outside the known infested area is prohibited by law unless the plants are free of all living forms of the beetle. Within the area affected by these regulations there are approximately 5,000 dealers in nursery stock and several large nurseries doing a national and international business. It is imperative that suitable methods for treating this stock be developed in order to prevent the serious disruption of the nursery industry within the regulated area.

During the years of 1920, 1926, 1927, 1928, and 1929 an investigation was carried on to determine the efficacy of immersing the subterranean portions of nursery plants in hot water as a method of treatment for the Japanese beetle. As a result of these experiments it is possible to recommend an effective method for exterminating this insect in the soil about the roots of certain nursery plants.

HOT-WATER IMMERSION FOR CONTROL OF OTHER SUBTERRANEAN PESTS

A study of the literature pertaining to the use of hot water to combat soil-infesting pests shows that immersion in hot water has been

used successfully to control nematodes, mealybugs, bulb flies, bulb mites, phylloxera, and other pests infesting the subterranean portion of nursery plants. At the present time one of the most satisfactory methods for controlling the narcissus bulb nematode (*Tylenchus dipsaci* Kühn), the bulb mites (*Rhizoglyphus echinops* Fumouze and Robin and *R. hyacinthi* Boisduval), the narcissus fly (*Merodon equestris* Fabricius) and the so-called lesser bulb flies (*Eumerus* spp.) consists in immersing the bulbs in water held at a temperature of 110° to 112° F. for a period of 3 hours (*5*, *6*, *9*, *11*, *14*, *19*, *20*, *24*.[1] The chrysanthemum nematode (*Aphelenchus ritzema-bosi* Schwartz) and the strawberry nematodes (*A. fragariae* R. B., *A. phyllophagus* Stewart, and *A. olesistus* R. B.) have been destroyed by immersing the dormant host plants in water at a temperature of 122° for 5 minutes (*16*, *22*). Nematodes have been killed on the roots of peonies by dipping the roots for 30 minutes in water at 120° (*2*). Grape stocks have been freed of the coccid *Pseudococcus maritimus* Ehrhorn and of the phylloxera *Phylloxera vastatrix* Planchon by immersing in water at 125° for 5 minutes (*1*, *15*). The mealybug *Pseudococcus maritimus* on gladioli has been destroyed by dipping the corms for 10 minutes in water at a temperature of 124° (*21*). The citrus-root nematode, *Tylenchulus semipenetrans* Cobb, has been controlled by immersing the subterranean portion of the citrus stock in water at a temperature of 120° for 15 minutes (*3*), or in water at a temperature of 130° for 30 seconds (*23*). Pots of soil infested with the root-knot nematode, *Heterodera radicicola* (Greef) Mueller, have been treated successfully by immersion for 5 minutes in boiling water (*4*).

From a study of the meager published information on the immersion of plants in hot water to exterminate subterranean insects and other closely related pests, it may be deduced that water at a temperature below 110° F. is usually ineffective in controlling pests and that water at a temperature above 130° is usually deleterious to the roots of plants. The temperature of the water and the period of immersion to be employed to exterminate the different pests are governed apparently by the susceptibility of the pest to hot water, the degree of protection given it by the host plant, and the resistance of the host plant to the treatment.

PREVIOUS WORK WITH HOT WATER ON THE JAPANESE BEETLE

Previous experiments by Leach (*13*) in 1920 with the third-instar larvae of the Japanese beetle demonstrated that this stage of the beetle could be destroyed by immersion in water at temperatures between 110° and 130° F. It was also found that the roots of *Chamaecyparis pisifera* and *Azalea amoena* could not be immersed in hot water without causing serious injury or death to the plants. When the phytopathological action of hot water on these plants was determined, the experiments with hot water as a soil insecticide were temporarily discontinued.

[1] Italic numbers in parentheses refer to Literature Cited, p. 40.

ACTION OF HOT WATER ON THE JAPANESE BEETLE

In 1926, when some preliminary tests indicated that certain other nursery plants were not seriously injured by immersing the roots in hot water, an extensive investigation was undertaken to determine the effectiveness of hot water in killing the different stages of the beetle under various conditions, and to determine the varieties of nursery plants that might be treated successfully.

EXPERIMENTAL TREATING TANK

During the course of this investigation several hot-water tanks were used for treating the plants and the different stages of the beetle. The tank which was finally developed and proved most satisfactory for this work was a specially equipped wooden tank [2] holding 300 gallons.

This experimental tank was constructed of selected 2-inch cypress. It was 6 feet long, 3 feet wide, and 2½ feet deep, inside measurements. The lumber was dressed, ripped, crozed, jointed, and reinforced with iron rods and wooden battens in the approved manner. The ends were boxed into the sides and bottom to a depth sufficient to insure the greatest strength. A partition of 1-inch cypress was placed inside across the end of the tank, parallel to and about 6 inches from one end, and extended to within 4 inches of the top. Two rectangular holes, each 10 inches high and 5 inches wide, were cut in the lower corners of this partition, and a circular hole 9 inches in diameter was cut on the median line near the bottom. Two solid partitions of the same material were constructed parallel to and 5 inches from each side of the tank. These extended from the end partition to the opposite end of the tank and from the bottom to within 6 inches of the top. Within this rectangular area, formed by the partitions and one end, was placed a false bottom with movable slats 4 inches wide made of 1-inch cypress.

A Monel-metal propeller, 8 inches in diameter, of the flat-pitch pusher type, was mounted on a shaft of the same material, three-fourths of an inch in diameter, and placed in the circular hole of the end partition. The shaft extended through a stuffing box in the end of the tank and was connected by means of a flexible coupling to an electric motor. This motor was one-third horsepower, making 1,730 revolutions a minute, and operated on a 110-volt, 60-cycle, alternating-current line. It was equipped with a gear reducer so that it would turn the agitator shaft at the rate of 440 revolutions per minute.

The water in the tank was heated by pumping hot water through a 14-foot coil of 2-inch galvanized-iron pipe, which was placed on the bottom of the tank. The water circulated through this coil was drawn from and returned to a 30-gallon tank of water held automatically at a temperature between 160° and 180° F. This boiler was of standard commercial type, heated by gas and equipped with a bimetallic thermostat. The water was forced through the heating

[2] The writers are indebted to F. E. Mehrhof, of Rutgers University, who drew the plans and aided in the assembling of this equipment.

coil by means of a centrifugal pump that discharged 30 gallons a minute in a closed system when the suction pressure was 15 pounds per square inch and the discharge pressure was 23 pounds per square inch. The one-half horsepower, 110-volt, 60-cycle, alternating-current motor, with a speed of 1,725 revolutions per minute, which operated the centrifugal pump, was controlled by a mercury-toluene thermostat which was placed in the tank. As the temperature in the tank fell below that at which the thermostat was set, the current flowing through the thermostat was broken, thus tripping a mercury switch and starting the motor operating the centrifugal pump.

For operation the tank was filled with water to within 2 inches of the top. The water was heated to approximately the desired temperature and the thermostat was then set at the exact temperature desired. The agitator was then started. The propeller drew the water from behind the end partition and forced it in a stream along the bottom towards the opposite end of the tank. Portions of this moving water were deflected upward at intervals by means of the slats, placed at various angles, in the false bottom. It flowed over the tops of the side partitions and was drawn behind the end partition again through the holes which were placed at the lower corners. A small amount of water, which was deflected upward a short distance from the propeller, returned behind the end partition by flowing over the top of this partition. This agitation caused a uniform, slow movement of the water throughout the treating chamber from one end to the other and from the bottom to the top.

NUMBER OF BEETLES USED IN EXPERIMENTS

Extensive experimentation with a soil-infesting insect such as the immature stages of the Japanese beetle is necessarily slow, laborious, and expensive. It is desirable to use in each test the minimum number of insects which will give reliable data. An experiment was therefore undertaken to determine the degree of accuracy of data based on different numbers of insects.

Two thousand third-instar larvae were dug at random in the field and treated by immersion in hot water for a period of time that killed the majority of them. The larvae were then placed in separate containers and numbered consecutively from 1 to 2,000. Thirty representative groups, each containing 10 larvae, were selected at random from the 2,000 larvae, with the aid of tables of logarithms, as is suggested by Jerome (*12*, *p. 18*). The percentage mortality and the magnitude of the probable error of the percentage was calculated for each group, using the formula $e=67.45\sqrt{\frac{pq}{n}}$ (*10*), where e is the magnitude of the probable error in per cent, p is the number of dead larvae, q is the number of living larvae, and n is the number of larvae examined. This procedure was repeated with representative groups containing 20, 30, 40, 50, 60, 70, 80, 90, 100, 150, 200, 300, and 400 larvae. The maximum percentage mortality, the minimum percentage mortality, the difference between these percentages, and the greatest probable error of the percentage mortality in per cent for each of these groups are outlined in Table 1.

TABLE 1.—*Reliability of a percentage mortality based on different numbers of Popillia larvae*

Larvae in group	Mortality of the group			Maximum probable error of percentage
	Maximum	Minimum	Difference	
Number	*Per cent*	*Per cent*	*Per cent*	*Per cent*
10	100.0	70.0	30.0	9.77
20	100.0	75.0	25.0	8.22
30	100.0	73.0	27.0	5.44
40	92.5	80.0	12.5	4.26
50	94.0	82.0	12.0	3.66
60	95.0	80.0	15.0	3.48
70	95.7	81.4	14.3	3.11
80	95.0	83.7	11.3	2.78
90	93.3	84.4	8.9	2.50
100	93.0	87.0	6.0	2.18
150	92.0	87.3	4.7	1.85
200	93.0	88.0	5.0	1.54
300	91.3	87.9	3.4	1.27
400	91.5	89.2	2.3	1.04

The data obtained in this experiment show that a group containing fewer than 100 larvae may be very unrepresentative. A percentage mortality based on a few larvae is likely to be inaccurate and may lead to erroneous conclusions. It was found that the probable error of the percentage mortality based on 10 larvae was 9.77 per cent, while the probable error of the percentage mortality based on 100 larvae was only 2.18 per cent. The difference between the maximum and the minimum percentage mortalities decreased progressively from 30 per cent with 10 larvae to 6 per cent with 100 larvae, and to 2.3 per cent with 400 larvae. These results are indicative of the probable error which would be obtained in the individual tests with the immature stages of the Japanese beetle. In view of the fact that the results, if favorable, were to be used as a basis for recommending a treatment that would be employed for quarantine purposes, it was decided to use not fewer than 200 of each stage in each test.

In carrying out this program the following numbers of the different stages of the beetle have been treated by immersion in hot water: 176,000 eggs, 21,000 first-instar larvae, 18,000 second-instar larvae, 308,000 third-instar larvae, 3,500 prepupae, 70,000 pupae, and 20,000 adults. Besides this, several thousand adults were kept in confinement to obtain eggs, and a large number of eggs were kept in the insectary to obtain the first-instar larvae when they hatched.

PROCEDURE USED IN STUDYING INSECTICIDAL ACTION OF HOT WATER

Although the immature stages of the beetle may be found in nurseries, the infestation is usually light, unevenly distributed, and difficult to locate. It was impossible to find a sufficient number of infested plants in nurseries to conduct extensive experimentation; artificial infestation of the roots of nursery plants generally proved to be a tedious and unsatisfactory procedure. It was decided, therefore, to make an extensive and intensive study of the insecticidal action of hot water on the beetle throughout its metamorphosis when the different stages were removed from soil, and then to determine the effectiveness of the treatment in destroying the insect in the soil.

It was not practical to obtain the large number of eggs required for experimental work by digging in infested fields, but eggs were obtained in almost unlimited quantities by confining adult beetles in cages with fresh smartweed (*Polygonum pensylvanicum*) and soil. The cage used for this purpose was a circular metal cage which was placed over a 10-inch flowerpot filled with moist, sifted soil, as shown in Figure 1. Eggs were removed from soil by means of a camel's-hair brush, and placed in groups of 100 in glass tubes, as shown in Figure 2. These tubes were 2 inches long, one-half inch wide, and had each end closed with an 80-mesh wire cap. The containers were then immersed in hot water, care being taken to have each tube completely filled with water. At the end of a definite period of time two tubes containing 200 eggs were removed from the water, and the eggs were transferred by means of a camel's-hair brush to the surface of moist leaf mold. The eggs were placed separately in small depressions on the surface of the leaf mold, as shown in Figure 3, and kept in the dark. They were examined daily for at least a month subsequent to treatment and records made of their condition. When an egg hatched, the larva was removed to prevent confusion in later observations. Each day when eggs were treated a group of 200 untreated eggs was set aside under the same environmental conditions to determine the rate of hatching of the untreated eggs throughout the season.

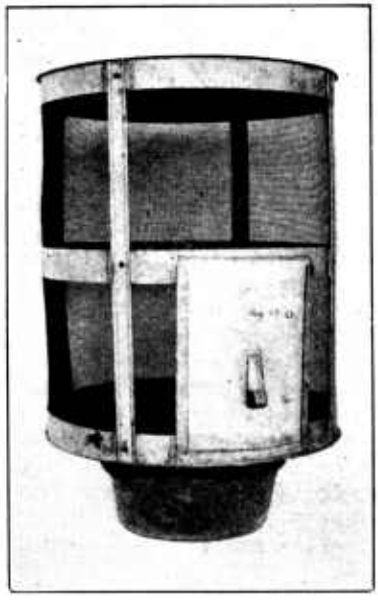

FIGURE 1.—Equipment used to obtain Japanese-beetle eggs in the insectary

The first-instar larvae used in these experiments were hatched in the insectary, but the second and third instar larvae were dug in fields which were apparently free from insect parasites and larval diseases. The first-instar larvae were treated in cages covered with 32-mesh wire as shown in Figure 4, A, and the second and third instar larvae were treated in cages covered with 20-mesh wire as shown in Figure 4, B. The larvae were placed in these cages, only one larva in each section to prevent them from injuring each other with their mandibles. Two hundred larvae were used as a unit in each test. After treatment, the first-instar larvae were placed on the surface of moist soil in the separate compartments of plaster-of-Paris molds, as shown in Figure 6; the second and third instar larvae were placed on moist soil in wooden cross-section trays, as shown in Figure 6. Each larva was observed daily and a record kept of its condition for a period of at least five days after treatment. In making the daily observation a record was made of the larvae which were dead, sick, and normal in each treatment. A larva was

considered to be dead when it remained on the surface of the ground, gave no reaction to external mechanical stimulation, and showed

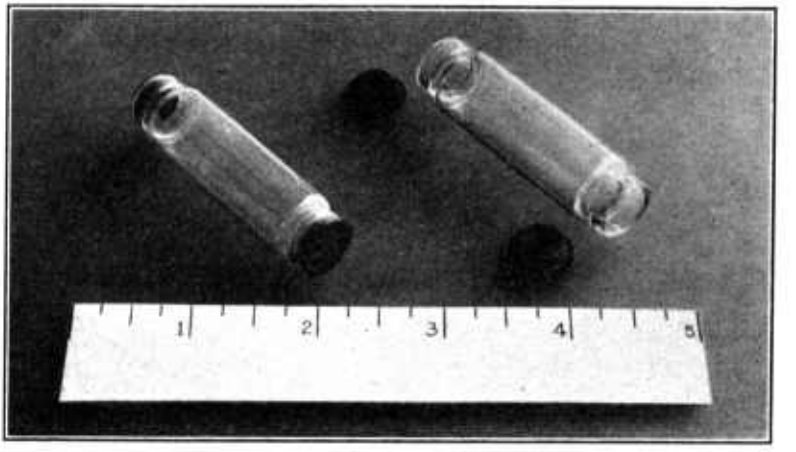

FIGURE 2.—Glass tubes used to confine Japanese-beetle eggs during treatment

signs of decomposition. It was considered to be sick when it remained on the surface of the ground and responded slowly to external mechanical stimulation. It was considered to be normal when it

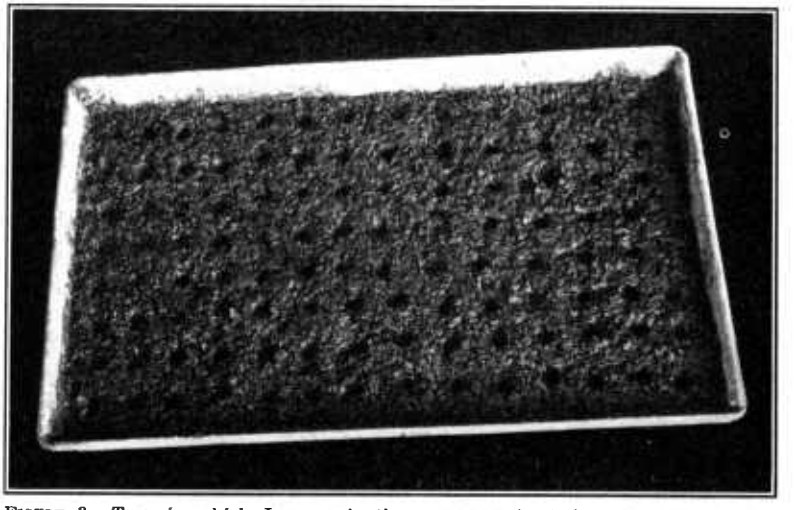

FIGURE 3.—Tray in which Japanese-beetle eggs were kept for observation after treatment

burrowed into the ground within a few hours after being placed on the surface and was apparently unaffected when removed at the end of the period of observation.

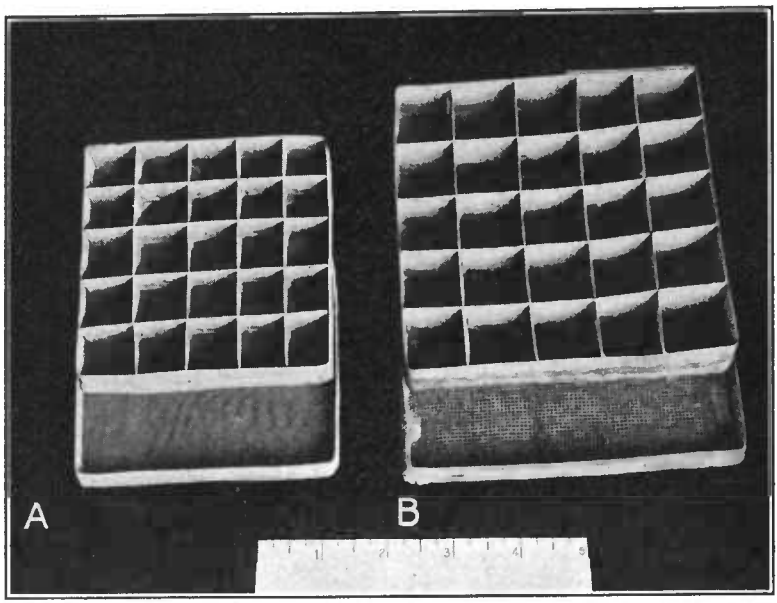

FIGURE 4.—Cages used to confine larvae, prepupae, and pupae of the Japanese beetle during treatment: A, With cover of 32-mesh screen; B, with cover of 20-mesh screen

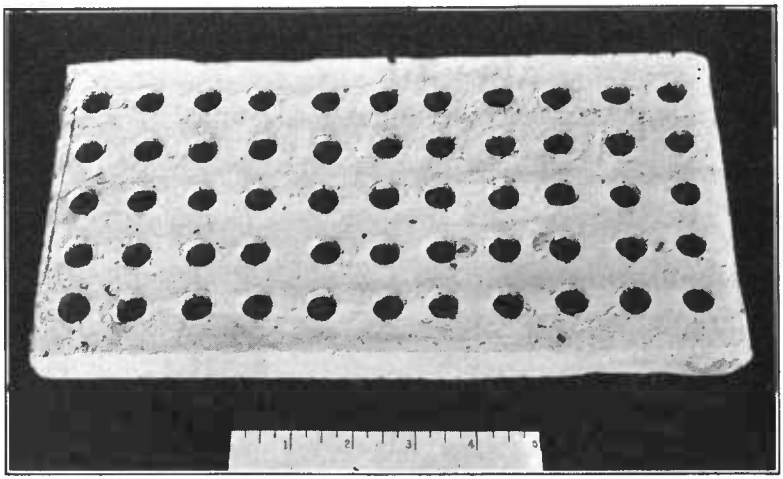

FIGURE 5.—Mold in which first-instar larvae of the Japanese beetle were kept for observation after treatment

The prepupae and pupae were dug in the field and treated in the same manner as third-instar larvae, except that it was found neces-

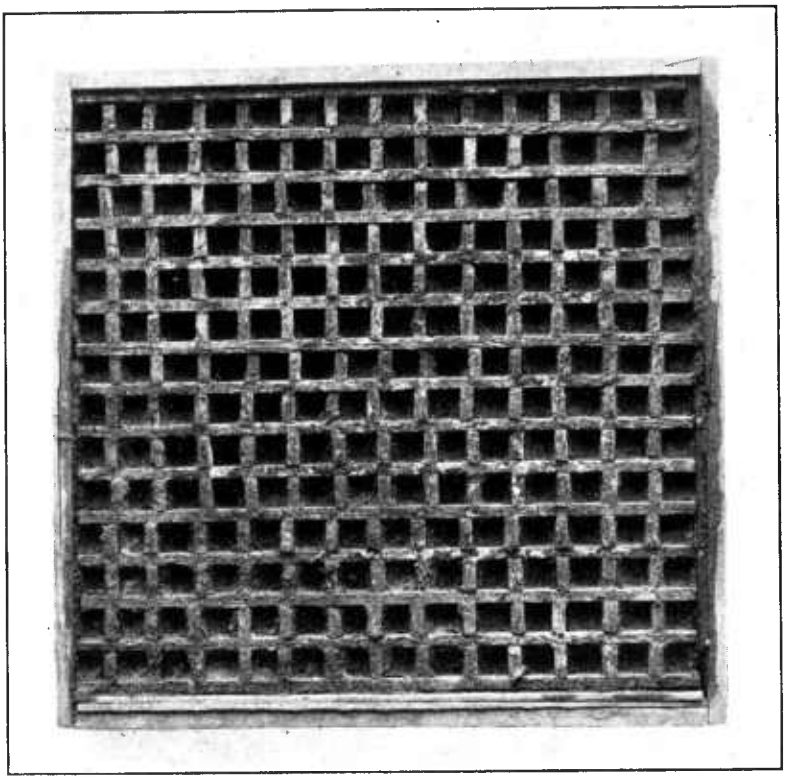

FIGURE 6.—Tray in which second and third instar larvae, prepupae, and pupae of the Japanese beetle were kept for observation after treatment

sary to keep them under observation for two to three weeks before making the final observations. The adults were collected from unsprayed weeds, shrubs, and fruit trees and treated in cylindrical cages

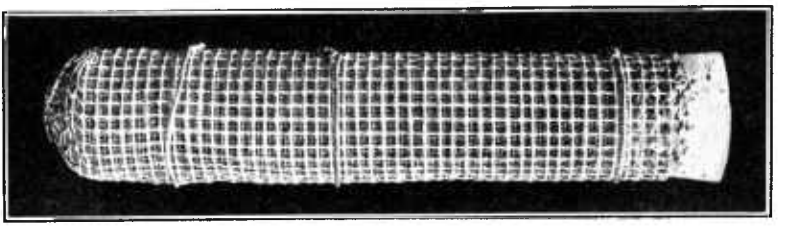

FIGURE 7.—Cage used to confine Japanese-beetle adults during treatment

of 8-mesh wire as shown in Figure 7. The adults were then placed in cages in the insectary and observed daily until the effect of the treatment could be determined.

RELATION OF TEMPERATURE OF WATER AND PERIOD OF IMMERSION TO INSECTICIDAL ACTION

In the fall of 1926 a preliminary study was made of the relation between the period of immersion and the temperature of the water to the insecticidal action. The tests were made with third-instar larvae because this stage of the insect is normally abundant during the fall of the year. Larvae were removed from soil and immersed in water at a temperature ranging from 100° to 130° F. The insects were kept in the water at each temperature for various intervals of time until the minimum lethal periods of immersion had been determined. The minimum lethal periods of immersion at temperatures between 100° and 130°, as determined in the fall of 1926, are outlined in the following tabulation:

Temperature:	Minimum lethal period (minutes)	Temperature:	Minimum lethal period (minutes)
100° F.	[1]480	118° F.	4
104° F.	340	120° F.	3
107° F.	170	122° F.	1
110° F.	70	124° F.	1
112° F.	31	126° F.	1
114° F.	16	128° F.	1
116° F.	10	130° F.	1

The destruction of the larvae at temperatures below 112° F. was found to be slow and often uncertain. As the temperature of the water was raised above 112°, the rate of larval destruction became greatly accelerated, until at 122° death was almost instantaneous. The minimum lethal period of 70 minutes at 110° was decreased to 31 minutes at 112°, and to 16 minutes at 114°. The rapidity of the insecticidal action was increased in the same manner as the temperature of the water was raised progressively by 2° above 114° until the thermal limit of 122° was reached.

THERMAL DEATH POINT

In this investigation the thermal death point was considered to be the lowest temperature at which death resulted after immersion for one minute. The thermal death point apparently varies with the metamorphosis of the insect, the season of the year, and other factors.

A study was made of the thermal resistance of the beetle throughout its metamorphic development. Eggs, larvae, prepupae, pupae, and adults were immersed for one minute in water at various temperatures until the thermal limit was determined. The tests were made continuously throughout the year, using all stages of the beetle which could be found in the soil. A summary of the data obtained at temperatures of 116°, 118°, 120°, 122°, 124°, 126°, 128°, and 130° F. in this experiment is given in Table 2.

[1] Not all the larvae were killed by immersion for this period of time.

TABLE 2.—*Tests to determine the thermal death point of the Japanese beetle at each stage in its development when immersed for one minute in hot water*

Temperature of water	Mortality of each stage of development						
	Egg	First-instar larva	Second-instar larva	Third-instar larva	Prepupa	Pupa	Adult
° F.	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
116	20.0	----------	----------	7.5	----------	42.5	25
118	55.0	74.0	----------	22.2	----------	----------	30
120	77.0	96.7	95.8	80.3	56.2	----------	80
122	83.5	99.8	100.0	96.2	93.9	87.4	100
124	93.6	100.0	100.0	99.9	99.5	98.3	100
126	99.9	100.0	100.0	100.0	100.0	99.7	100
128	100.0	100.0	100.0	100.0	100.0	100.0	100
130	100.0	100.0	100.0	100.0	100.0	100.0	100

It was found that the thermal limit of the beetle varies throughout its life cycle. The thermal death point of the insect during its embryonic development is 128° F. The larva after it emerges from the egg is destroyed at 122°, and there is little change in susceptibility to heat during the first and second larval instars. After the second postembryonic molt the thermal limit is raised to 126° and remains at this point until the larva approaches maturity when it is decreased to 122°. After the larva changes into a prepupa, the thermal death point is raised to 126°. During the pupal stadium the thermal limit is 128°, but when the pupa transforms into the adult the insect is destroyed at 122°.

A study was also made of the relation between the season and the thermal death point of the insect. The tests were made with third-instar larvae because the duration of this stage is the longest. The larvae were treated continuously throughout the year whenever it was possible to dig them in the field. From the results of this experiment it was found that during the summer and early fall, when the larva is feeding extensively, the thermal limit is 122° F. With the approach of winter the activity of the larva decreases and it becomes more tolerant to heat. When it becomes quiescent the thermal death point is raised to 126° and it remains at this point throughout the winter. In the spring, when the larva resumes intensive feeding it becomes more susceptible to heat and the thermal limit is lowered to 122°.

INSECTICIDAL ACTION OF WATER AT 112° F.

Although the insecticidal action of water heated to the thermal death point of the beetle was quick and effective, it was found that the treatment of the roots of nursery plants at this temperature was often dangerous to the plants. It was also found that soil immersed in water at a temperature of 110°, 112°, 116°, or 120° was heated throughout to the temperature of the water at approximately the same rate. The period of time necessary to heat soil from 112° to 120° was sufficient in most cases to have destroyed the larvae at the

lower temperature. Plants treated at the higher temperature, therefore, would be subjected to a more vigorous treatment than would be necessary to obtain the desired insecticidal action. At 112°, the lowest temperature at which quick and dependable insecticidal action took place, it was found that many plants were uninjured. The necessarily prolonged soaking at temperatures below 112° had a retarding effect on the subsequent growth and in some cases killed the plants. In view of these results, treatment at 112° was selected as having the most promise of successful application to the subterranean portions of nursery plants. A preliminary report on the insecticidal action of water at 112° has been published by the writers (*7*).

RESISTANCE OF EGGS

The study of the resistance of eggs to the insecticidal action of water at 112° F. was carried on during the summers of 1927, 1928, and 1929. The eggs were carefully removed from soil and immersed in water at a temperature of 112° for periods of time ranging from 10 to 90 minutes. A summary of the results obtained is given in Table 3.

TABLE 3.—*Results of treatment of Japanese-beetle eggs with water at 112° F.*

Period of immersion	Mortality			Period of immersion	Mortality		
	Maximum	Minimum	Average		Maximum	Minimum	Average
Minutes	*Per cent*	*Per cent*	*Per cent*	*Minutes*	*Per cent*	*Per cent*	*Per cent*
10	93.0	0	58.0	60	100.0	82.5	98.1
20	94.0	47.0	75.4	65	100.0	79.5	98.9
30	99.0	30.0	78.2	70	100.0	96.0	99.7
40	100.0	24.0	91.4	75	100.0	95.5	99.8
45	98.0	62.5	80.2	80	100.0	98.0	99.9
50	100.0	80.5	97.3	85	100.0	100.0	100.0
55	100.0	80.5	94.5	90	100.0	100.0	100.0

In Table 3 the maximum mortality is the highest mortality of a group of 200 eggs at each period of immersion; the minimum mortality is the lowest mortality of a group of 200 eggs; and the average mortality is the mortality of all eggs treated for each period of time.

It was found necessary to prolong the period of immersion to 85 minutes to destroy all of the eggs, but extermination was practically obtained in 70 minutes. The few eggs which hatched after treatment for 70 minutes were greatly retarded in development and the larvae did not emerge until several days after the larvae had emerged from untreated eggs. Of the eggs treated for 70, 75, and 80 minutes only 0.28, 0.25, and 0.05 per cent, respectively, were able to complete their embryonic development and emerge as larvae.

Further study of the data showed that there is a great difference in the resistance of different groups of eggs to the action of hot water. For example, 32 groups of eggs were treated by immersion for 40 minutes. The resulting mortalities were as follows: Nine groups

had 100 per cent mortality, 9 groups had 95 to 99 per cent, 7 groups had 90 to 94 per cent, 3 groups had 85 to 89 per cent, and the remaining 4 groups had 81, 71, 64, and 24 per cent mortality. The average mortality of the 32 groups was 91.4 per cent. When the period of immersion was increased to 70 minutes, the average mortality of the 39 groups was raised to 99.72 per cent, but still a few of the groups had a lower mortality. Of these 39 groups, 32 groups had 100 per cent, 5 had 99 per cent, 1 had 98 per cent, and the last had 96 per cent mortality. It is apparent that the majority of the eggs are susceptible to the insecticidal action of water at 112° F., and only a small proportion of them are abnormally resistant.

RESISTANCE OF FIRST-INSTAR LARVAE

The study of the resistance of first-instar larvae to the insecticidal action of water at 112° F. was made during August and September of 1927, 1928, and 1929. The larvae were removed from soil and immersed for periods of 10, 15, 20, 25, 30, 35, 40, 45, and 50 minutes respectively. A summary of the mortality resulting from each of these treatments is given in Table 4.

TABLE 4.—*Results of treatment of first-instar larvae with water at 112° F.*

Period of immersion	Mortality			Period of immersion	Mortality		
	Maximum	Minimum	Average		Maximum	Minimum	Average
Minutes	*Per cent*	*Per cent*	*Per cent*	*Minutes*	*Per cent*	*Per cent*	*Per cent*
10	100	6	76.0	35	100	96	99.5
15	100	86	95.8	40	100	100	100.0
20	100	90	98.3	45	100	100	100.0
25	100	98	99.6	50	100	100	100.0
30	100	98	99.7				

It was found that although treatment for 10 minutes occasionally destroyed all the larvae in a test, consistent total destruction was not obtained under 40 minutes. Treatment of first-instar larvae for 25 minutes is practically exterminative, since only 0.35 per cent of the larvae survived after immersion for this period of time.

RESISTANCE OF SECOND-INSTAR LARVAE

The study of the larval resistance to the insecticidal action of water at 112° F. was continued with second-instar larvae during August, September, and October. A summary of the effect of the treatments on the second-instar larvae is given in Table 5.

TABLE 5.—*Results of treatment of second-instar larvae with water at 112° F.*

Period of immersion	Mortality			Period of immersion	Mortality		
	Maximum	Minimum	Average		Maximum	Minimum	Average
Minutes	*Per cent*	*Per cent*	*Per cent*	*Minutes*	*Per cent*	*Per cent*	*Per cent*
10	100.0	12.0	67.7	30	100	100	100
15	92.5	91.0	91.7	35	100	100	100
20	100.0	96.0	98.4	40	100	100	100
25	100.0	96.5	99.4				

It was found in these tests that all the second-instar larvae were destroyed by immersion for a period of 30 minutes. It would appear that the second-instar larva is more susceptible to heat than is the first-instar larva. An examination of the results obtained with both instars shows there was not more than 0.5 per cent difference between them in treatments lasting more than 20 minutes. This difference probably is not significant. If the tests had been made with 50,000 instead of 10,000 larvae of each stage, probably there would have been no apparent difference between the two stages. Although it was not demonstrated that some second-instar larvae would withstand treatment for 35 minutes, the results obtained with both instars would lead one to believe that the period of immersion should be prolonged to 40 minutes to insure the destruction of the most resistant larvae of this instar.

RESISTANCE OF THIRD-INSTAR LARVAE

The study of the resistance of third-instar larvae to immersion in water at 112° F. was carried on during the fall, winter, and spring of 1927, 1928, and 1929. The larvae were removed from soil and immersed for periods ranging from 10 to 75 minutes. A summary of the results obtained with the different tests is given in Table 6.

TABLE 6.—*Results of treatment of third-instar larvae with water at 112° F.*

Period of immersion	Mortality			Period of immersion	Mortality		
	Maximum	Minimum	Average		Maximum	Minimum	Average
Minutes	*Per cent*	*Per cent*	*Per cent*	*Minutes*	*Per cent*	*Per cent*	*Per cent*
10	100	38.0	67.1	45	100	90.5	99.0
15	99	28.5	74.7	50	100	89.0	99.2
20	100	53.5	97.7	55	100	91.0	99.2
25	100	76.0	96.5	60	100	97.5	99.5
30	100	81.0	99.0	65	100	97.6	99.5
35	100	91.0	98.6	70	100	100.0	100.0
40	100	86.0	99.1	75	100	100.0	100.0

It was found necessary to continue the treatment for 70 minutes to destroy the most resistant third-instar larvae. There is a considerable variation in the susceptibility of third-instar larvae to the action of hot water. In some tests with immersion for 10 minutes, for example, all larvae were killed; when the treatment was applied to another group, the mortality was decreased to 38 per cent. The

average mortality of the larvae immersed for 10 minutes was 67.1 per cent. The third-instar larvae were practically destroyed by immersion for 40 minutes, since less than 1 per cent survived after treatment for this period of time.

RESISTANCE OF PREPUPAE

The study of the resistance of prepupae was carried on in June. The treatment was applied to prepupae in the same manner as to the larvae. The results of these tests are given in Table 7. It was found that prepupae were destroyed by immersion for 45 minutes in water at 112° F.

TABLE 7.—*Results of treatment of prepupae with water at 112° F.*

Period of immersion	Mortality			Period of immersion	Mortality		
	Maximum	Minimum	Average		Maximum	Minimum	Average
Minutes	*Per cent*	*Per cent*	*Per cent*	*Minutes*	*Per cent*	*Per cent*	*Per cent*
5	----------	----------	[1] 39.0	30	97	73.5	89.0
10	----------	----------	[1] 41.0	35	99	91.5	97.3
15	47	19	33.0	40	100	99.0	99.8
20	93	29	58.8	45	100	100.0	100.0
25	79	69	74.7	50	100	100.0	100.0

[1] Only one treatment was made for this period of time.

RESISTANCE OF PUPAE

The investigation of the resistance of pupae to the insecticidal action of hot water was carried on during 1927, 1928, and 1929. The results of these tests, which are summarized in Table 8, show that pupae were destroyed by immersion for 70 minutes in water at 112° F.

TABLE 8.—*Results of treatment of pupae with water at 112° F.*

Period of immersion	Mortality			Period of immersion	Mortality		
	Maximum	Minimum	Average		Maximum	Minimum	Average
Minutes	*Per cent*	*Per cent*	*Per cent*	*Minutes*	*Per cent*	*Per cent*	*Per cent*
5	21.0	7.0	14.0	40	100	83.5	95.4
10	20.0	20.0	20.0	45	100	67.0	96.9
15	----------	----------	[1] 32.0	50	100	92.5	98.1
20	74.0	34.0	57.4	55	100	90.0	98.8
25	90.5	83.5	87.2	60	100	91.0	99.2
30	96.5	66.5	83.7	65	100	97.5	99.5
35	98.5	72.0	88.0	70	100	100.0	100.0

[1] Only one treatment was made for this period of time.

RESISTANCE OF ADULTS

A study of the resistance of the adult beetle to hot water was made during the summer. The results of the different tests are summarized in Table 9. It was found that treatment for 20 minutes was sufficient to destroy the adult beetle.

TABLE 9.—*Results of treatment of adults with water at 112° F.*

Period of immersion	Mortality			Period of immersion	Mortality		
	Maximum	Minimum	Average		Maximum	Minimum	Average
Minutes	*Per cent*	*Per cent*	*Per cent*	*Minutes*	*Per cent*	*Per cent*	*Per cent*
10	84	84.0	84.0	25	100	100.0	100.0
15	100	99.7	99.9	30	100	100.0	100.0
20	100	100.0	100.0				

RECAPITULATION OF THE RESISTANCE OF DIFFERENT STAGES

A study of the resistance of the eggs, larvae, prepupae, pupae, and adults to immersion in water at 112° F. shows that all stages of the insect, with exception of the eggs, can be destroyed by continuing the treatment for 70 minutes. It was found that this treatment prevented 99.72 per cent of the eggs from hatching and seriously impaired the normal development of the larvae which emerged. It is therefore considered that immersion of the beetle at any stage of its metamorphosis for 70 minutes in water at a temperature of 112° F. is practically exterminative.

HIGHLY RESISTANT BEETLES

It was repeatedly observed, during the course of the insecticidal tests at 112° F., that a small percentage of the beetles throughout their development were abnormally resistant to the action of heat. This condition was more apparent with eggs, third-instar larvae, and pupae which are difficult to kill than it was with the other stages which succumb readily. It was found that 99 per cent of the eggs, third-instar larvae, and pupae were destroyed by treatment for 60, 40, and 55 minutes, respectively. For complete destruction it was necessary to prolong the treatment of eggs to 85 minutes, and the treatment of the larvae and pupae to 70 minutes.

The abnormally high resistance of a small proportion of the beetles to insecticidal action can not be explained satisfactorily. The decrease in susceptibility is probably not an innate quality but is the complex resultant of ecological and physiological factors. The question of resistance of the beetle is of considerable importance, particularly when the treatments are to be used as quarantine measures. It was therefore decided to continue this phase of the hot-water investigation in order to accumulate further information and to safeguard the recommendations which have been based on the data accumulated to date.

EFFECT OF WEATHER ON RESISTANCE

A study was carried out during three years with the object of correlating the variation in the resistance of a stage of the beetle with the meteorological conditions. Experiments were conducted with eggs, larvae, prepupae, pupae, and adults, but only the third larval stadium was found to be of sufficient duration that the resistance was affected appreciably by the weather.

It is difficult to elucidate on the relation of weather to the resistance of a soil-infesting insect under field conditions, because it is practically impossible to separate the complex meteorological factors. The soil temperature and soil moisture appeared to be the most important of the soil factors in modifying the resistance of the immature stages of the beetle.

The minimum lethal period of immersion for third-instar larvae was determined at weekly intervals during the fall, winter, and spring. A summary of the results obtained during 1927, 1928, and 1929 is given in Table 10.

TABLE 10.—*Resistance of third-instar larvae throughout the stadium to treatment with water at 112° F.*

Period of immersion (minutes)	Percentage mortality in—									
	September	October	November	December	January	February	March	April	May	June
10	68.3	53.8						43.3	76.3	95.3
15		75.8	28.5							93.5
20	99.9	96.6	83.5					100.0	99.9	99.5
25	99.3	95.0	90.0						100.0	99.5
30	100.0	98.4	91.0					100.0	100.0	99.8
35	100.0	99.5	96.8	94.0				98.7	100.0	100.0
40	100.0	100.0	98.6	99.7	95.6	96.0	98.4	99.8	100.0	100.0
45	100.0	100.0	98.6	100.0	97.6	100.0	98.8	99.8	100.0	100.0
50	100.0	100.0	98.9	98.9	98.5	100.0	99.2	100.0	100.0	100.0
55	100.0	100.0	98.8	99.8	99.1	100.0	98.8	100.0	100.0	100.0
60	100.0	100.0	99.1	98.9	100.0	100.0	99.7	100.0	100.0	100.0
65	100.0	100.0	99.2	99.6	100.0	100.0	99.2	100.0	100.0	100.0
70	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
75	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

A study of the soil-moisture conditions prevailing in the vicinity of Moorestown, N. J., showed that although the differences in the amount of precipitation in different weeks was often considerable, there was apparently sufficient moisture in the ground to satisfy the normal requirements of the larvae. The rainfall in Moorestown is generally relatively constant and fairly evenly distributed throughout the year. From May to August most of the rain occurs with thunderstorms. Snowfall is usually light, remaining on the ground but a short time, and there are many winters without appreciable snow. In general, it appears that in a humid region there will usually be sufficient moisture in the soil to permit the larvae to develop normally. Soil moisture in this region, therefore, probably will not become an important factor influencing the resistance of the larvae to insecticidal treatments.

The change in the resistance of the larvae to hot water is apparently influenced by the temperature of the soil within the upper 6 inches, but it was not possible to correlate the daily fluctuations of temperature with the resistance. It was found possible to correlate the general trend of the temperature with the general trend of the resistance. With a minimum temperature of the soil above 60° F. in September, larvae are destroyed by immersion for 30 minutes; in October, with the minimum temperature lowered to 55°, treatment

must be prolonged to 40 minutes; in November, with the normal minimum approaching 43°, the theoretical temperature of quiescence, the minimum period of immersion must be increased to 70 minutes. The period of quiescence continues throughout the winter and early spring until the minimum temperature rises above 43°. The larvae are very resistant to insecticidal treatment during this quiescent period but become more susceptible as they resume activity in the spring. In April larvae are destroyed by treatment for 50 minutes, and in May, when the soil temperature remains above 55°, the minimum period of immersion is reduced to 25 minutes.

A study of the available Weather Bureau reports on the weather at Moorestown for 65 years (*17*) shows that in this vicinity there are likely to be frequent and abrupt changes in temperature, but only rarely do severe temperature reversals occur. The normal temperature ranges from 30.7° in January to 74.7° in July, although a temperature of 0° may occur between the latter part of December and the end of February, and a temperature above 100° may occur in the summer. The average minimum soil temperatures at a depth of 6 inches at Moorestown were found to follow closely the normal temperature of the air.[4]

In other regions the change in resistance of the larvae may come at different periods of the year than at Moorestown, but it is improbable that the weather conditions in any section will increase the resistance to such an extent that immersion for 70 minutes in water at 112° F. will not prove fatal.

IMPORTANCE OF MAINTAINING TEMPERATURE CONSTANT

In the preliminary study of the relation between the temperature of the water, the period of immersion, and larvicidal action, it was found that the minimum time necessary to kill all of the larvae could be modified considerably by changing the temperature only 2°. When the temperature of 112° F. had been selected as the most practical temperature for treatment, an intensive study was made of the effect on the insecticidal action of varying the temperature of the water by 2° above and below 112°. The temperature of the water was held within 0.5° of 110°, 112°, or 114° throughout the course of the treatments.

Eggs, larvae, prepupae, pupae, and adults were immersed in water at these temperatures without soil for periods of time ranging from 10 to 120 minutes. Many different periods of immersion were tested, but only the results from those periods which are increments by 10 minutes are given in Table 11.

[4] The data on soil temperatures were furnished by Henry Fox, under whose direction the meteorological data of this laboratory are recorded.

TABLE 11.—*Results of treatment of different stages of the Japanese beetle with water at 110°, 112°, and 114° F.*

Period of immersion	Temperature	Mortality of—						
		Eggs	First-instar larvae	Second-instar larvae	Third-instar larvae	Prepupae	Pupae	Adults
Minutes	*° F.*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
10	110	58.0	76.0	67.7	67.1	41.0	20.0	29.0
	112	62.9	99.9	93.4	77.0	69.7	70.7	84.0
	114	69.6	86.3	74.5	89.5	48.0	35.0	100.0
20	110	75.4	98.3	98.4	97.7	58.8	57.4	63.0
	112	91.3	99.9	100.0	99.3	99.5	92.6	100.0
	114	73.9	96.0	88.7	87.9	57.0	27.0	100.0
30	110	78.2	99.7	100.0	99.0	89.0	83.7	99.5
	112	99.6	100.0	100.0	99.9	100.0	99.9	100.0
	114	71.8	99.3	98.0	95.6	58.0	41.3	100.0
40	110	91.4	100.0	100.0	99.1	99.8	95.4	100.0
	112	99.9	100.0	100.0	100.0	100.0	100.0	100.0
	114	83.0	99.3	99.7	98.4	80.0	73.0	100.0
50	110	97.3	100.0	100.0	99.2	100.0	98.1	100.0
	112	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	114	79.4	100.0	100.0	94.5	90.4	79.2	100.0
60	110	98.1	100.0	100.0	99.5	100.0	99.2	100.0
	112	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	114	81.4	100.0	100.0	95.0	94.8	91.2	100.0
70	110	99.7	100.0	100.0	100.0	100.0	100.0	100.0
	112	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	114	93.1	100.0	100.0	97.9	99.7	94.0	100.0
80	110	99.9	100.0	100.0	100.0	100.0	100.0	100.0
	112	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	114	95.2	100.0	100.0	98.9	100.0	95.9	100.0
90	110	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	112	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	114	92.6	100.0	100.0	99.5	100.0	97.6	100.0
100	110	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	112	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	114	96.6	100.0	100.0	99.1	100.0	98.8	100.0
110	110	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	112	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	114	97.6	100.0	100.0	99.1	100.0	99.2	100.0
120	110	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	112	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	114	98.9						
130	110	100.0						
	112	100.0						
	114	99.6						
140	110	100.0						
	112	100.0						
	114	99.8						
150	110	100.0						
	112	100.0						
	114	100.0						
160	110	100.0						
	112	100.0						
	114	100.0						

The results of these tests show that if, in applying the treatment, the temperature of the water is inadvertently kept at 110° instead of 112° F., not all of the insects would be killed within a period of 70 minutes. In these tests, when the water was held at 110°, 18.6 per cent of the eggs, 5 per cent of the third-instar larvae, 5.2 per cent of the prepupae, and 8.8 per cent of the pupae survived the insecticidal action. In order to destroy the different stages of the insect at 110° it was necessary to immerse the eggs for 160 minutes, first and second instar larvae for 60 minutes, third-instar larvae for more than 120 minutes, prepupae for 90 minutes, pupae for more than 120 minutes, and adults for 40 minutes. If, on the other hand, the temperature of the water is allowed to rise above 112°, the insecticidal action will be accelerated. In these tests all stages of the beetle were extermi-

nated by immersion for 50 minutes in water at a temperature of 114°.

It was also found that when the period of immersion at 112° was reduced to 60 minutes, the most resistant of the eggs, third-instar larvae, and pupae were not killed. The treatment was even less effective when the beetle was immersed in water at 110° for 60 minutes. In the latter treatment, 20.6 per cent of the eggs, 5.5 per cent of the third-instar larvae, 9.6 per cent of the prepupae, and 20.8 per cent of the pupae survived. Other examples of decreased effectiveness when the temperature of the water is lowered to 110°, or the period of treatment is less than 70 minutes, may be seen by consulting Table 11.

These data, which were accumulated during three years, emphasize further the importance of maintaining careful control over the temperature of the water and prolonging the treatment for a sufficient period of time to secure the insecticidal action.

INSECTICIDAL ACTION IN SOIL

When the insecticidal action of water at a temperature of 112° F. had been established with the different stages of the beetle that had been removed from soil, a study was made to determine the effectiveness of the treatment in destroying infestations in soil. Experimental work on the effectiveness of hot water in soil was carried on in the laboratory, in the greenhouse, and in the nurseries.

In the laboratory, masses of soil of different types, volumes, and composition were artificially infested with third-instar larvae. The procedure which was found to be the most satisfactory in preparing these masses of soil was as follows: An earthen flowerpot of the desired volume was partially filled with the soil to be tested, five larvae were placed on the soil, and then sufficient soil was added to fill the pot. The pot was then inverted on washed, moist muslin and carefully removed in such a manner that the form in which the soil had been molded was not destroyed. The soil was then tightly wrapped in the muslin and tied. Forty masses of the same type and volume were prepared for each test so that the effect of the treatment could be observed on at least 200 larvae. Thermometers were inserted through the muslin into the soil in such a manner that the mercury bulbs were at the centers of the masses of soil. The artificially infested masses of soil were then immersed in water. When the temperature recorded on the thermometer showed that the center of the mass of soil had reached a temperature of 112° F., the soil was held in the water for an additional 70 minutes. The soil bags were then removed from the hot water and suspended to drain until the soil was sufficiently dry that the larvae could be removed without causing mechanical injury. The larvae were removed from soil and kept under observation in the same manner as was used in studying the insecticidal action on larvae that had been removed from soil before treatment.

It was found that larvae were destroyed in sandy loams, clay loams, sand, and peat, when the soils were either wet or dry, and varied in volume up to 1 liter, by immersing the infested masses of soil in water at 112° F. and continuing the treatment for 70 minutes

after the soil masses had been heated throughout to the temperature of the water. In many cases groups of 200 larvae were destroyed by holding the soil at 112° for less than 70 minutes. It is apparent that the period of preheating has a certain insecticidal action which tends to decrease the period of treatment necessary at 112°.

In the greenhouse the soil about the roots of hydrangeas growing in 6-inch earthen pots was infested artificially by placing five active third-instar larvae on the surface of the soil in small depressions and allowing them to burrow into the soil. After a week the larvae were found to be distributed throughout the soil in the pots. Some larvae were feeding on the roots in contact with the sides of the pots; others were feeding on the roots near the center of the masses of soil. Thermometers were inserted into the masses of soil and roots in such a manner that the mercury bulbs were at the centers of the masses. The potted plants were then placed in water at a temperature of 112° so that the soil was completely immersed and the aerial portions were above the water, and kept in the water for 70 minutes after the soil had been heated throughout to 112°. After treatment the plants were returned to the greenhouse bench. When the soil had dried sufficiently to be friable, the soil was shaken from the roots and a careful search was made for the larvae in each pot. The larvae which were recovered were kept under observation until the effect could be definitely determined. It was found that the treatment of the infested hydrangeas was successful, all larvae being destroyed.

In the nurseries, groups of Dahlia, Phlox, Iris, and Paeonia, which had been dug previously from infested fields, were prepared for shipment according to the regular procedure by removing excess soil, dividing the clumps, and pruning the roots. The plants were then immersed in water at a temperature of 112° F. and held for 70 minutes after the masses of soil about the roots had been heated to the temperature of the water. The plants were then removed and examined. The cavities in the roots were cut open, tangled masses of roots were divided, crevices dug out, and all adhering soil broken up to find any larvae which might be hidden in the plants. After a long, tedious examination of over 5,000 plants, all larvae of the Japanese beetle were found to have been destroyed as were also some larvae of Phyllophaga, some elaterid larvae, earthworms, and millepedes.

It was apparent from these experiments that hot water could be relied upon to destroy the immature stages of the beetle in the soil about the roots of plants, provided the infested soil was immersed in water at a temperature of 112° F. and maintained in the water for 70 minutes after it had been heated to 112°.

HEATING SOIL BY IMMERSION IN HOT WATER

Having ascertained that the Japanese beetle is destroyed by immersing the infested soil in water at 112° F., a study was made of the factors affecting the penetration of heat into soil under these conditions. When a mass of soil at room temperature is immersed in water held at 112° F., hot water flows into the soil, displacing practically all the air and filling the interstices with water. The inrush-

ing hot water gives up some of its heat to the particles of soil, raising the temperature of the soil 20° to 30°. After the initial increase in temperature, heat penetrates from the water surrounding the soil and gradually raises the temperature of the soil and its absorbed water to 112°. The period of time required to heat a mass of soil to 112° under these conditions depends on many factors, among which the most important are the volume, type, temperature, and absorptive power of the soil.

The volume of the soil modifies considerably the period of time necessary to heat it. When bog soil about the roots of cultivated blueberries was immersed in water at 112° F., the period of time required to heat the soil to this temperature was extended greatly with a slight increase in the size of the mass of soil. When the soil and roots were in compact, roughly spherical masses of approximately 2 inches in diameter and containing about 8 cubic inches in volume, 27 minutes were necessary to heat them to 112°. The average periods of time required to heat larger volumes of this soil and roots are as follows: 27 cubic inches in 57 minutes, 64 cubic inches in 61 minutes, 216 cubic inches in 80 minutes, 512 cubic inches in 90 minutes, 1,728 cubic inches in 205 minutes, and 3,375 cubic inches in 390 minutes. There was, however, considerable variation in the time required to heat masses of soil and roots of the same volume. The minimum time required to heat 8 cubic inches of peat soil was 5 minutes, but the maximum time was 70 minutes. The heating of clay loam in earthen flowerpots was very similar to the heating of the bog soil about the roots of blueberry plants. Two cubic inches of clay loam in a 1½-inch clay pot was heated from room temperature to 112° on the average in 14.5 minutes. The heating of larger volumes of clay loam in pots was accomplished in the following periods of time: 5 cubic inches in 18.4 minutes, 6.6 cubic inches in 19.8 minutes, 16 cubic inches in 29.9 minutes, 26 cubic inches in 37.6 minutes, 39 cubic inches in 48.9 minutes, and 53 cubic inches in 55.6 minutes. Similar results were obtained with different volumes of sand, sandy loam, clay, and peat moss. It was apparent from a study of the rates of heating different volumes of soil to 112° that several hours are required to heat relatively large masses of soil to the temperature of the surrounding water. If it is necessary to limit the hot-water treatment to those masses of soil which can be heated to 112° within a period of 60 minutes in order to make the method practical to use in the nurseries, it will be necessary to confine the treatment to those plants which have less than 64 cubic inches of soil about their roots.

The penetration of heat into soil immersed in hot water is affected by the type of the soil. Thirty-nine cubic inches of moist sandy loam in a 4-inch earthern pot was heated in 32 minutes; clay loam under the same conditions required 49 minutes; and a peat soil required 72 minutes to be heated to the temperature of the surrounding water.

The temperature of the mass of soil before immersion affects the period of heating required. Soils which are at a temperature of 35° to 50° F. required from 10 to 30 minutes longer treatment, depending upon the volume, than did soils which were at 65° to 75°.

The soil should be warm to reduce as much as possible the period of preheating.

The period of time required to heat a soil to 112° is affected by the quantity of water absorbed by the soil when immersed. Soils which are saturated with water before being placed in hot water are heated more slowly than soils which are only partially saturated with water. After the rapid increase in temperature caused by the inrush of hot water, the temperature will increase more slowly. The heat capacity of water is approximately five times that of dry particles of soil (*18*). It is apparent, therefore, that soils, such as peat, which absorb a high percentage of water, will heat more slowly than sandy soils which have a limited absorptive power.

A comparative study was made of the time required to heat sandy loam to the temperature of the surrounding water when the temperature of the water was 100°, 110°, 115°, or 120° F. It was found that the time required to raise the temperature of the soil to that of the surrounding water was practically the same within the range of 100° to 120°.

There are many intrinsic factors involved in the penetration of heat into a mass of soil immersed in hot water. It was found impossible to predict accurately the period required to heat the soils about the roots of the different nursery plants. It was decided, therefore, to determine the period of heating required in each treatment by the following procedure: Select several plants with the largest masses of soil about their roots and insert thermometers in such a manner that the mercury bulbs are approximately at the center of each mass of soil and roots. Place these plants last in the hot water and observe constantly until the thermometer is at a temperature of 112° F. When the last of these inserted thermometers registers 112° all of the masses will be at this temperature.

EFFECT OF HOT-WATER TREATMENT ON NURSERY PLANTS

PRELIMINARY WORK IN 1926–27

Through the cooperation of interested nurserymen, 1,500 plants of 87 varieties were made available for experimentation with hot water. The plants were prepared for treatment by removing the loose soil, dividing the large clumps of roots, and pruning the tops and roots. The plants were treated while dormant during the winter of 1926–27 by immersing the roots in water at temperatures of 108°, 110°, and 112° F. for periods of 100, 60, and 40 minutes, respectively. The plants were then potted and placed in the greenhouse for observation. Four months after the application of the treatment the condition of the plants indicated that 64 of the varieties had not been appreciably affected by the hot water and 23 of them had been killed or greatly retarded in development. In view of the successful treatment of the majority of the plants in this preliminary experiment, the writers were encouraged to proceed with experimentation on a much larger scale at the laboratory and in commercial nurseries. A preliminary report on the effect of hot water on nursery plants has been published (*8*).

EXPERIMENTS AT THE LABORATORY

After the successful results in the preliminary experiment had been obtained, a group of varieties in which commercial nurserymen were particularly interested was selected for further experimentation. These plants included *Azalea* spp., *Berberis* sp., *Dahlia* sp., *Forsythia* sp., *Hydrangea* spp., *Iris* spp., *Paeonia* spp., *Phlox* spp., *Picea* sp., *Rhododendron* sp., *Spiraea* spp., *Syringa* sp., *Vaccinium* sp., and *Weigela* sp.

TREATMENT OF AZALEA SPP.

During the winter of 1926 experiments were begun to determine the effect of the hot-water treatment on the greenhouse azalea, *Azalea indica*, and on the decorative azalea, *A. amoena*. The roots of the semidormant, 3-year-old, indica azaleas, including the varieties Empress of India, Jean Haerens, Mme. Petrick, Mme. Van der Cruyssen, Professor Walters, Simon Mardner, and Vervaene, were immersed in water at temperatures of 100°, 108°, 110°, 112°, and 114° F. for different periods of time after the masses of soil had been heated to the temperature of the water. The periods of preheating varied from 70 to 140 minutes, depending upon the volume and the condition of the soil held by the roots. The plants were then potted and placed in warm and cool greenhouses for observation. It was found that the immersion of the roots of *A. indica* in hot water at any temperature for an insecticidal period had a decidedly detrimental effect on the plants. The flower buds were completely destroyed, the weaker plants killed, and the vigorous plants seriously retarded in their subsequent growth. When the treatment was applied to *A. indica* in the early fall, before the plants had reached the stage of dormancy of the winter plants, the result was equally disastrous. The immersion of the roots of *A. amoena* in hot water was also fatal to the plants.

TREATMENT OF BERBERIS SP.

Three-year-old plants of red Japanese barberry, *Berberis thunbergi atropurpurea*, were dug in the field in the fall and placed in storage. During the winter the roots were immersed for insecticidal periods in water at temperatures of 100°, 108°, 110°, 112°, 114°, 116°, 118°, and 120° F. The treated plants along with some untreated plants were planted in a warm greenhouse for observation. It was found that the immersion of the roots in hot water at any of these temperatures for an insecticidal period had a deleterious effect on the plants. After treatment the roots became soft, spongy, and discolored, and the tops became dry and hard. A month after the roots were immersed in hot water the plants were dead or so severely injured as to be of no value.

Red barberry plants were dug in the field during April, May, and October, treated by immersion in water at 112° F., and replanted in the field. It was found that the red barberry was very sensitive to the action of hot water on its roots and was killed by this treatment readily at any time of the year.

TREATMENT OF DAHLIA SP.

Clumps of dahlias of several common varieties were dug in the field in the fall of 1926, surface-dried, and placed in cool, aerated cellars. In the early winter of 1926–27, roots were immersed for insecticidal periods in water at temperatures of 100°, 108°, 110°, 112°, 114°, 116°, 118°, and 120° F. The period required to heat the soil adhering to the clumps to the temperature of the water was in no case greater than 20 minutes. Some of the treated roots were potted and placed in warm greenhouses along with untreated roots of the same varieties. All of the roots which were treated at temperatures above 108° grew normally in the pots as shown in Figure 8 and produced flowers that were equal to those of the untreated roots of the same varieties. The roots which were treated at 100° were killed by the prolonged immersion in the hot water. Another group of these treated roots was packed, while wet, and placed in storage. When these roots were examined in early spring, it was found that many of them had rotted. A third group of these roots was carefully surface-dried, then stored in a cool, well-aerated cellar; and in the spring these roots were found to be in good condition.

In late spring of 1927 a group of dahlia roots was immersed for 70 minutes at 112° F., in addition to the 15 minutes required to heat the clumps to this temperature. When the roots were removed from the water it was found that all of the eyes which had grown an inch or more were killed; the eyes which were not so far advanced were apparently unaffected. The roots were planted in the field and grew normally. The flowers on these treated plants were equal in every respect to those on untreated plants of the same varieties.

During the winter of 1928 dahlia roots were treated by immersion in water at 112° F., carefully dried, and placed in a mixture of peat and soil on greenhouse benches. As the eyes on the roots developed, the new sprouts were removed and planted in pots, according to the procedure used in the vegetative propagation of the newer varieties. The results obtained with the treated roots were equal in every respect to those obtained with untreated roots. The varieties which were treated and used successfully for propagation purposes included: Barbara Snow White, Bob Newcombe, Bob Pleuse, Cactus, Elite Glory, Flambuoyant, Fellowes, Geisha, Granada, Hera, His Majesty, Jean Chazot, Jersey Empress, Jersey Sovereign, Josephine Mendillo, Lemonade, Lillian Baldwin, Little Beauty, Little Jewel, L. W. Alton, Margaret Woodrow Wilson, Marion, Midget, Mme. Gygax, Nagel's Glory, Oasis, Riverton Golden Glow, Rodman Wanamaker, Skagerrak, Sun Maid, Sunny South, Tango Century, Wapiti, and Yukon.

TREATMENT OF FORSYTHIA SP.

The weeping forsythia, *Forsythia suspensa*, was dug in October, when dormant, the loose soil removed from the roots, and the roots immersed in water at 112° F. for periods of 70, 90, and 110 minutes. The plants were then planted in the field. In February some of the plants which had been treated for each period of time along with some untreated plants were dug, potted, and brought into a warm greenhouse. The treated plants grew normally and flowered the

same as the untreated plants. The treated plants could not be distinguished from the untreated plants in the field during the next growing season.

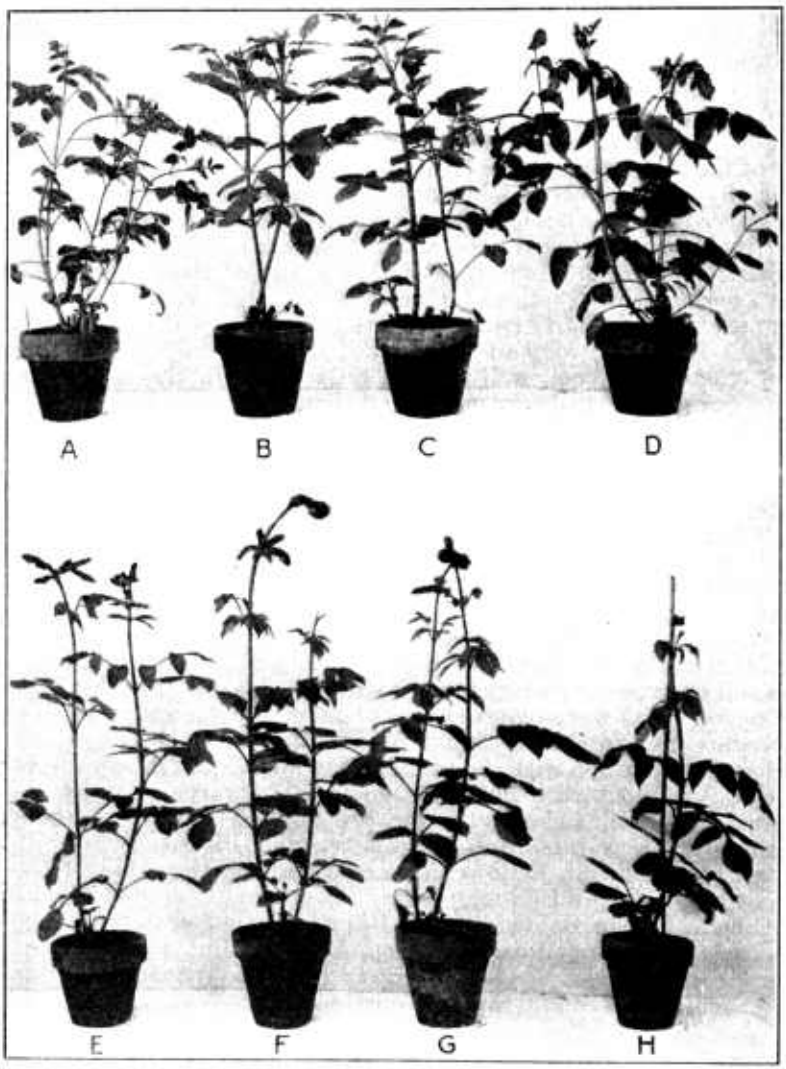

FIGURE 8.—A, Dahlia plant grown from untreated root; B, to H, dahlia plants grown from roots treated with hot water at 108°, 110°, 112°, 114°, 116°, 118°, and 120° F., respectively

TREATMENT OF HYDRANGEA SPP.

During the winter the house hydrangea, *Hydrangea opuloides*, including the varieties Baby Bimbenet, Domotii, E. G. Hill, General de Vibraye, Mme. E. Chautard, Mme. E. Mouillère, Otaksa, Radiant,

and Suzanne Cayeux, were immersed for insecticidal periods in water at temperatures of 100°, 108°, 110°, and 112° F. The plants were dormant and were well established in 6-inch pots at the time of treatment. It required from 70 to 100 minutes to heat the soil in these pots to the treating temperatures. After treatment the plants were divided into two groups. One group was placed immediately in a warm greenhouse; the other was kept in a cool greenhouse for a period of six weeks and then brought into the warm greenhouse. It was found that treatment at 100° F. had killed the plants and treatment at the other temperatures had retarded to some extent the subsequent development. The injurious action of hot water was more apparent on those plants which were held in the cool greenhouse for six weeks before being brought into a growing temperature. Most of the plants which were placed in the warm house after treatment produced practically normal flowers, as shown in Figure 9, A to D, although the plants did not have the vigorous appearance of the untreated plants. The plants which were kept cool for a period were stunted in growth and few of them produced normal blooms, as shown in Figure 9, E to H.

In August, 1929, the house hydrangea, *H. opuloides*, was treated while growing actively by immersing the roots in water at a temperature of 112° F. for a period of 70 minutes after the soil about the roots had been heated to this temperature. Some of the plants were dug in the field and had all of the loose soil removed from the roots before treatment; others were dug and potted in 4-inch, 5-inch, and 6-inch pots before the roots were immersed in the hot water. After treatment, all of the plants were placed in pots and set in the field. The varieties which were treated included America, Avalanche, Baby Bimbenet, Caprice, Coquelicot, Domotii, Eclaireur, E. G. Hill, Elmar, General de Vibraye, La Marne, Lancelot, Louis Mouillère, Marechal Foch, Mme. Agnes Barillet, Mme. Auguste Nonin, Mme. E. Chautard, Lilie Mouillère, Mme. René Jacquet, Otaksa, Splendens, Success, William Pfitzer, and Yvonne Cayeux. Within a few days after the treated plants were placed in the field the leaves and the terminals of the stems began to wilt. The plants never recovered from the effect of the hot water on the roots, and by the end of the first month were dead.

The smooth hydrangea, *H. arborescens*, was dug in the field while dormant and treated by immersing the roots in water at 112° F. for 70 minutes after the soil had been heated to this temperature. The plants were set in the field immediately after treatment. During the summer of 1928 the treated plants were retarded in growth as compared with the untreated plants.

TREATMENT OF IRIS SPP.

During the winter the crested iris (*Iris cristata*), the tall bearded iris (*I. pallida* and *I. variegata*), the fringed iris (*I. japonica*), the yellowband iris (*I. ochroleuca*), the yellowflag iris (*I. pseudacorus*), and the Siberian iris (*I. sibirica*) were immersed, while dormant, in water at a temperature of 112° F. and kept in the water for 70 minutes after the soil about the roots had been heated to this temperature.

They were then planted in the field. During the following summer the treated iris of all species, with the exception of *I. ochroleuca*, could not be distinguished from the untreated plants of the same species growing in the field. *I. ochroleuca* seemed to be somewhat retarded in development during the first season.

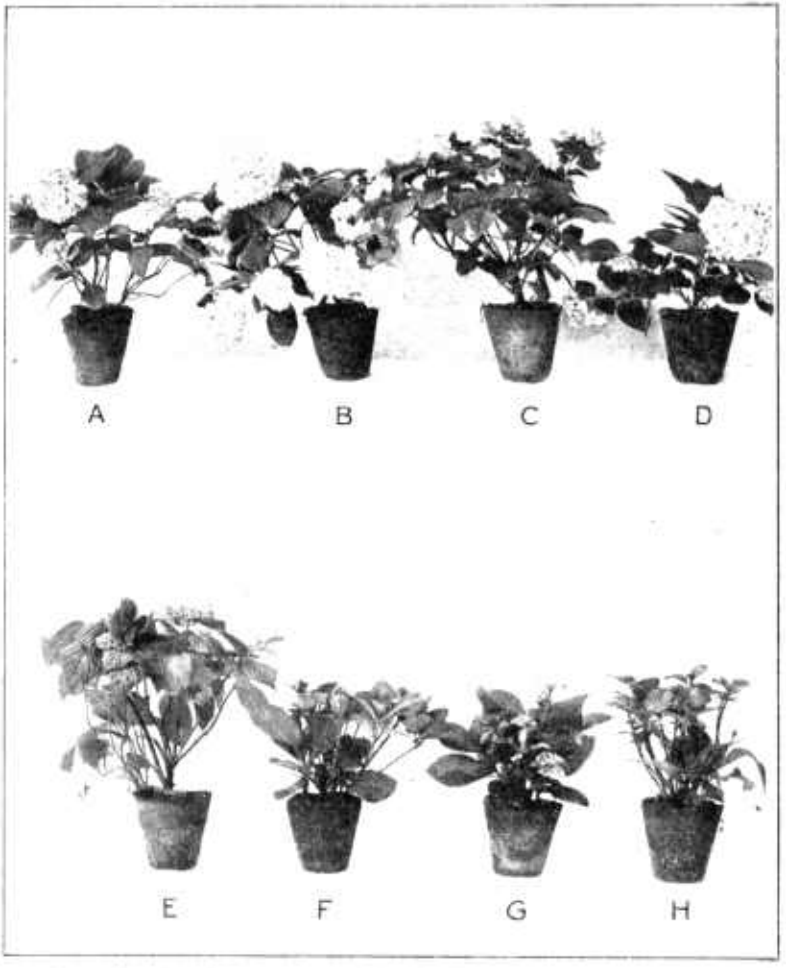

FIGURE 9.—A to D, Hydrangeas from plants kept in a warm greenhouse 4 months; A and B, untreated; C and D, treated with hot water at 110° F.; E to H, hydrangeas from plants kept in a cool greenhouse for 1½ months and in a warm greenhouse for 2½ months; E, untreated; F to H, treated with hot water at 108°, 110°, and 112° F., respectively

In August, 1928, the varieties Celeste of *I. pallida* and Spectabilis and Sherwin-Wright of *I. variegata* were immersed in water at 112° F. for periods of 70, 80, 90, 100, and 110 minutes. The plants were set out in the nursery, where they grew and bloomed normally the following season, as shown in Figure 10. Iris has been treated during February, March, September, October, November, and De-

cember without any apparent detrimental effects. Treated iris, when properly dried and packed, have been kept several months in storage and then, after planting, have grown normally.

TREATMENT OF PAEONIA SPP.

The dormant roots of *Paeonia* spp. were removed from storage and immersed for insecticidal periods in water at temperatures of 100°,

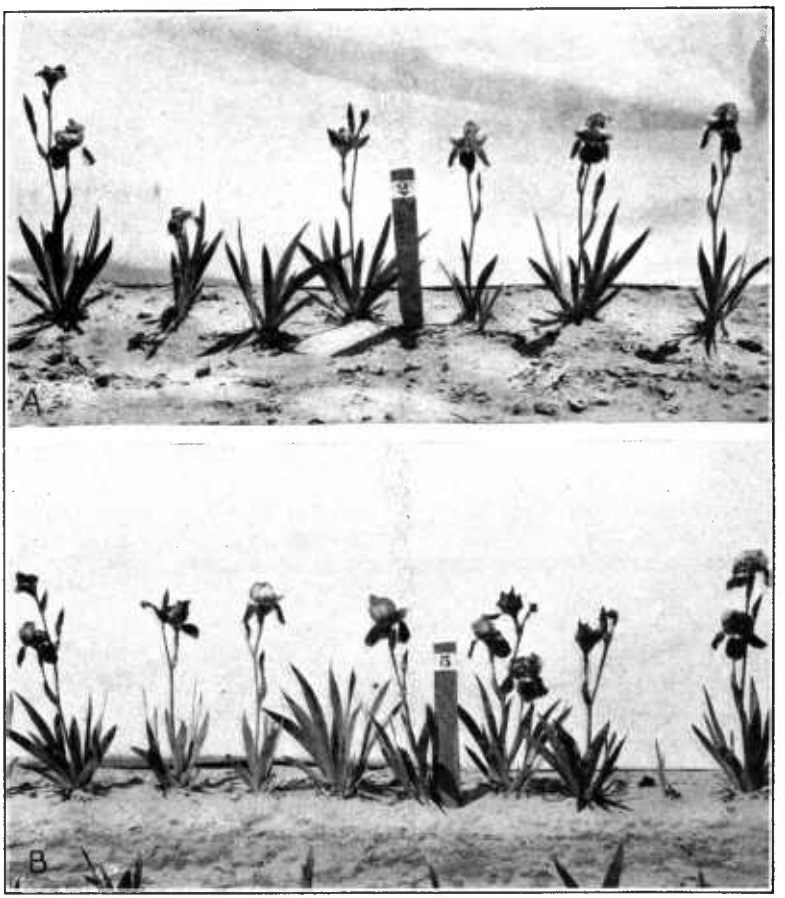

FIGURE 10.—Iris plants: A, From untreated roots; B, from roots treated with hot water at 112° F. for 70 to 110 minutes

108°, 110°, 112°, 114°, 116°, 118°, and 120° F. The roots were then potted and placed in a warm greenhouse. The plants grew and were equal in every respect to the untreated plants, with the exception of those that had been treated at 118° and 120°. (Fig. 11.) The roots treated at these higher temperatures were retarded somewhat in development, although not seriously affected. The treatment at 112° was also applied for 75, 100, and 125 minutes without causing any deleterious effect on the plants.

The varieties Albert Crousse, Avalanche, Baroness Schroeder, Berlioz, Canari, Charlemagne, Duchesse de Nemours, Edulis Superba, Eugene Verdier, Festiva Maxima, L'Indispensable, Livingstone, Louis Van Houtte, Marie Jacquin, Meissonier, Mme. Emile Galle, Mlle. Leonie Calot, Mons. Jules Elie, and Sarah Bernhardt

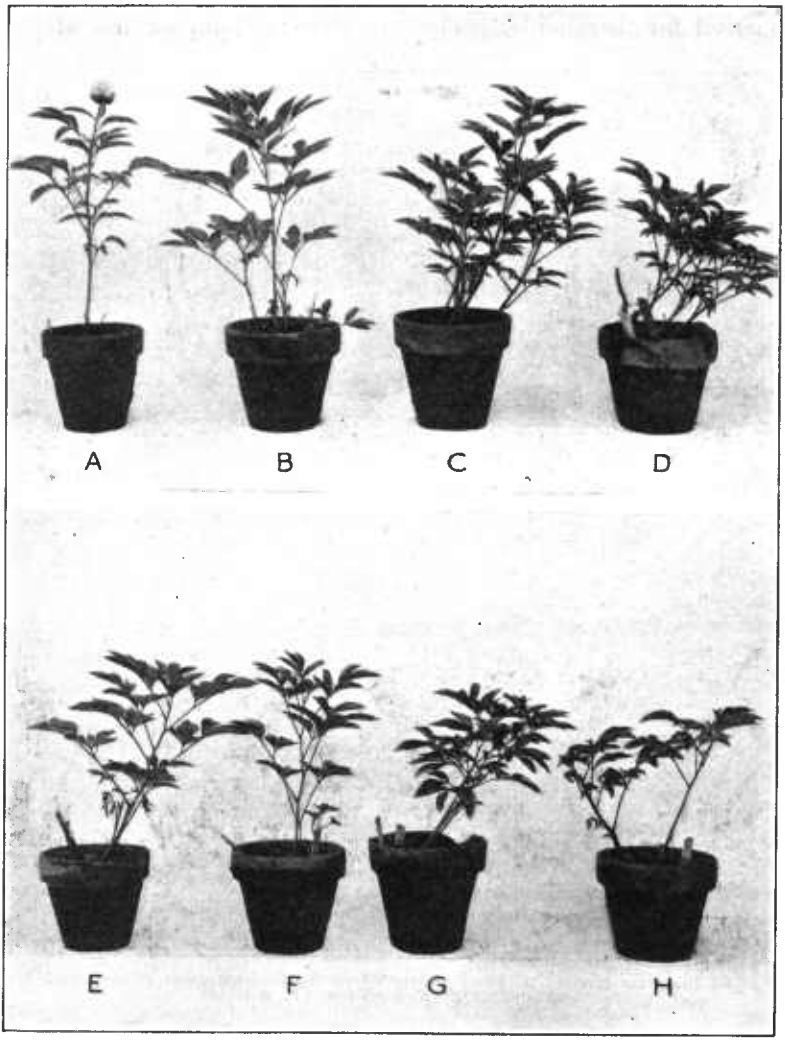

FIGURE 11.—Peony plants: A, From untreated root; B to H, from roots treated with hot water at 108°, 110°, 112°, 114°, 116°, 118°, and 120° F., respectively

have been treated successfully by immersing the roots in water at 112° F. for 70 minutes after the soil about the roots had been heated to this temperature. Treatment has been applied successfully during January, February, March, August, September, October, November, and December. The treated Paeonia roots grew normally even when kept in cold storage for several months after treatment.

TREATMENT OF PHLOX SPP.

During the winter, amoena phlox (*Phlox amoena*), the smooth phlox (*P. glaberrima suffruticosa*), the garden phlox (*P. paniculata*), and several horticultural varieties of phlox were immersed

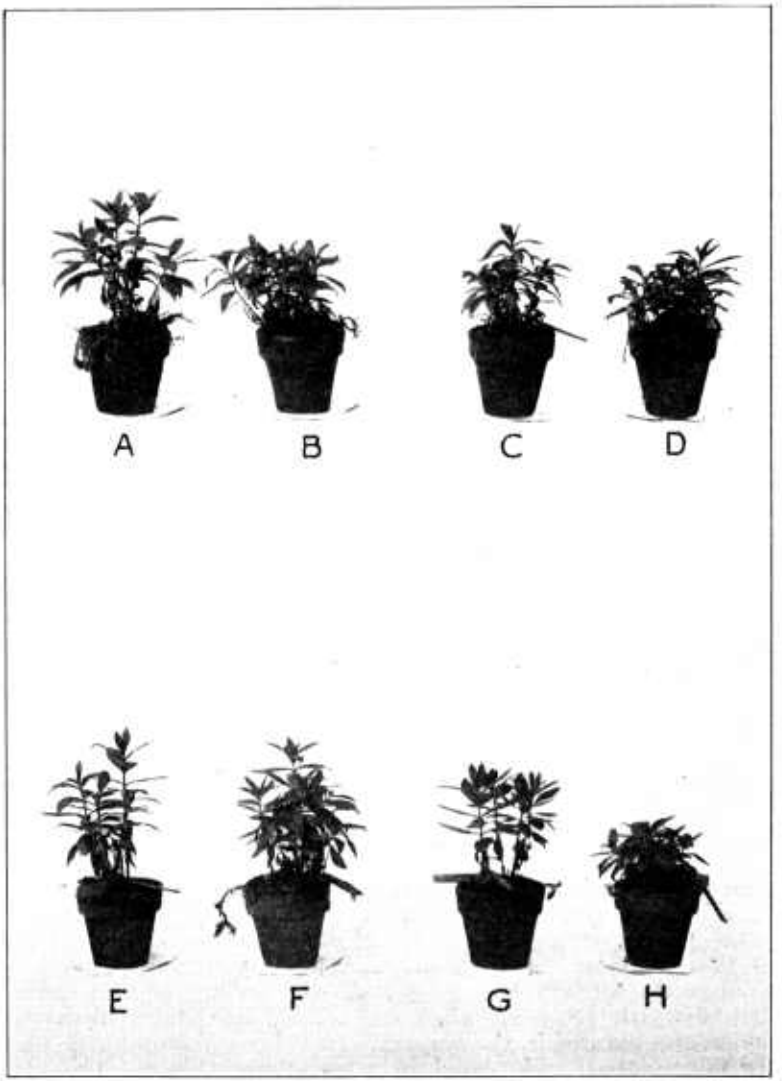

FIGURE 12.—Phlox plants: A, From untreated roots; B to H, from roots treated with hot water at 108°, 110°, 112°, 114°, 116°, 118°, and 120° F., respectively

while dormant for insecticidal periods in water at temperatures of 108°, 110°, 112°, 114°, 116°, 118°, and 120° F. The plants were then potted and placed in a warm greenhouse. All of the treated plants grew normally, as shown in Figure 12.

The varieties Champs Elysee and Mrs. Jenkins were immersed in water at 112° F. for periods of 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, and 150 minutes. All of the plants grew normally except those that had been in the water for over 120 minutes. The plants that were immersed for long periods of time were somewhat retarded in development.

The varieties Albion, Bacchante, Bridesmaid, Champs Elysee, Jacquiline Maille, Jeanne d'Arc, La Vague, L'Esperance, Louise Abbema, Mia Ruys, Mrs. Jenkins, Rheinlander, Rijnstroom, and Thor have been treated successfully by immersing the dormant plants in water at 112° for a period of 70 minutes after the soil masses have been heated to this temperature.

TREATMENT OF PICEA SP.

Colorado spruce (*Picea pungens*) was dug in the nursery in early spring. The mass of soil about the roots was secured by means of a burlap wrapping, such as is employed in the commercial nurseries. The roots were then immersed in water at 112° F. and held in the water for periods of 40, 50, 60, and 70 minutes after the soil had been heated to the temperature of the water. The trees were then planted in the nursery. The hot-water treatment, even for a period of 40 minutes, was very detrimental to Colorado spruce. Within 10 days after treatment the foliage began to drop, and by the end of a month the trees were brown and dead.

TREATMENT OF RHODODENDRON SP.

The varieties Caractacus, Catawbiense, Everest, John Walter, and Sir Henry Havelock of *Rhododendron catawbiense* were dug in the field on September 29, 1927, and treated by immersing the roots in water at 112° and holding the plants in the water for 70 minutes after the soil about the roots had been heated to this temperature. It required 160 minutes to heat the soil about the roots of these rhododendrons to 112° F. The plants were set out in the nursery and never recovered from the action of the hot water on the roots. All the treated plants died.

TREATMENT OF SPIRAEA SPP.

Spiraea bumalda, variety Anthony Waterer, was treated in January, while dormant, by immersing the roots in water at a temperature of 112° F. for 70 minutes. A period of 30 minutes was required to heat the soil about the roots to this temperature. The plants were set out in the nursery and grew normally during the next summer.

Bridalwreath (*S. prunifolia*) was treated in October in the same manner, and planted in the nursery. In February some of the plants were dug, potted, and placed in a warm greenhouse. The plants grew and produced normal blooms in the greenhouse. During the following season the treated bridalwreath in the field grew and bloomed the same as the untreated plants.

TREATMENT OF SYRINGA SP.

The common lilac, *Syringa vulgaris*, when dormant in October, was immersed in water at 112° F. for periods of 70, 90, and 110 minutes, and then planted in the nursery. In February some of the plants were dug, potted, and placed in a warm greenhouse. The plants which were forced into early growth and those which were left in the field all grew normally and produced flowers during the growing season.

TREATMENT OF VACCINIUM SP.

Cultivated blueberries (*Vaccinium* sp.), including the varieties Adams, Cabot, Dunfee, Grover, Harding, Katherine, Pioneer, Rancocas, Rubel, and Sam, were dug in the field, and after excess soil had been shaken from the plants the roots were immersed in water at 112° F. and held for a period of 70 minutes after the soil had been heated to this temperature. The period of preheating required

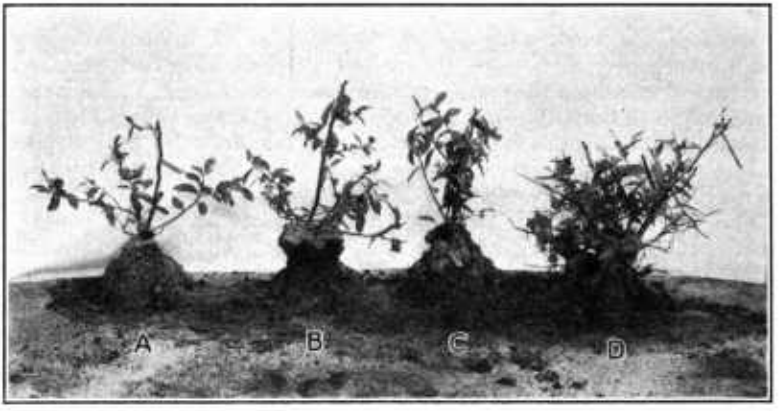

FIGURE 13.—Vaccinium plants about seven weeks after treatment of roots with hot water: A, Pioneer; B, Cabot; C, Rubel; D, Harding

varied from 20 to 255 minutes, depending upon the volume and the condition of the soil about the roots. Some of the treated plants were set in the nursery a few hours after treatment; others were packed and shipped to different growers. Although treatments were applied during September, October, November, December, January, February, March, April, and May, when the plants were in different stages of growth, the plants were apparently unaffected, and developed normally, as illustrated by Figure 13. There is, of course, less hazard in treating the plants in late fall, winter, or early spring, when the plants are dormant, or semidormant, than in treating during the actively growing seasons.

TREATMENT OF WEIGELA SP.

Pink weigela (*Weigela rosea*) was dug in October, when dormant, and treated by immersing the roots in water at 112° F. for 70 minutes after the soil had been heated to this temperature. The plants

were then set out in the nursery. In February, some of the plants were dug, potted, and brought into a warm greenhouse. These plants which were forced into growth and those left in the field grew normally and produced flowers during the growing season.

RECAPITULATION OF LABORATORY TESTS WITH PLANTS

The results obtained in the laboratory experiments with different plants showed that treatment with hot water was fatal to certain evergreens—*Azalea* spp., *Rhododendron* sp., and *Picea* sp.; that the treatment was successful with certain herbaceous perennial plants—*Dahlia* sp., *Iris* spp., *Paeonia* spp., and *Phlox* spp.; that the treatment was successful with some deciduous shrubs, such as *Forsythia* sp., *Spiraea* spp., *Syringa* sp., and *Weigela* sp., but fatal to *Berberis* sp. and *Hydrangea* spp. It seemed possible that the treatment could be applied successfully to some of the herbaceous perennials and deciduous shrubs, but could not be used on some evergreens.

EXPERIMENTS IN COMMERCIAL NURSERIES

Most of the work with plants was carried on cooperatively with the nurserymen who were interested in obtaining information on varieties with which they were particularly concerned. This arrangement made it possible to experiment with a large number of plants without involving the expenditure of Government funds, but because of the nature of the work it was possible to obtain only limited information on some varieties of plants.

The treatment so far as possible was made an extra step in the usual procedure of the nursery in preparing the different varieties for market. The herbaceous plants, such as *Iris* spp., *Phlox* spp., *Dahlia* sp., and *Paeonia* spp., were prepared for treatment by removing loose soil, dividing the large clumps, and pruning the tops and roots. *Berberis* sp., *Lonicera* spp., *Spiraea* spp., and other deciduous shrubs were prepared for treatment by removing the loose soil and pruning the roots. The bulk of soil about the roots of *Azalea* spp. and *Rhododendron* sp. was reduced as much as possible without injuring the plants. Potted plants such as ferns and *Hydrangea* spp. were not prepared in any special manner for treatment.

All plants, with the exception of the ferns and some varieties of hydrangea, were treated while dormant or semidormant. The small herbaceous plants were packed loosely in wire baskets, or other suitable containers which would permit free circulation of water, and were immersed completely in the hot water, since it was practically impossible to treat only the subterranean portions of these varieties. The other plants were placed in the water in such a manner that only their roots were immersed. The plants were heated until the temperature of the soil about the submerged parts was 112° F. and then held at this temperature for a period of 70 minutes.

Each variety was handled after treatment according to the usual commercial practice of the nursery. No attempt was made to handle the treated plants more carefully than the untreated stock, as it was maintained by the nurserymen that the treatment, to be practical, had to be successful under ordinary commercial conditions, without the exercise of special care for the plants. Some varieties were

packed within a few hours in crates and placed in cold storage; other varieties were potted and set in greenhouses or coldframes; other varieties were planted outside in soil free of infestation. The treated plants were kept under close observation and were compared frequently with untreated plants of the same species under the same condition. The plants that were apparently unaffected by the treatment were sold at the end of the season.

The varieties of plants which were treated, and the effect of the treatment on their subsequent growth, is outlined briefly in Table 12 for convenient reference. It is apparent that with proper care a large number of plants may be treated successfully to destroy the immature stages of the Japanese beetle by immersing the subterranean portions of the plants in water at a temperature of 112° F.

TABLE 12.—*Effect of immersion in water at 112° F. for 70 minutes on dormant plants*

Name of plant		Condition of the plant after treatment
Scientific name	Common name	
Achillea filipendulina	Fernleaf yarrow	Killed.
ptarmica	Sneezewort	Retarded.
Adiantum pedatum	American maidenhair	Killed.
Ajuga reptans	Carpet bugle	Normal.
Allium schoenoprasum	Chive	Do.
Amsonia tabernaemontana	Willow amsonia	Do.
Aquilegia chrysantha	Golden columbine	Killed.
flabellata nana-alba	White fan columbine	Do.
skinneri	Mexican columbine	Normal.
vulgaris nivea	Munstead white columbine	Killed.
Arenaria montana	Mountain sandwort	Normal.
Arrhenatherum bulbosum	Tuber oatgrass	50 per cent killed; 50 per cent retarded.
Aster novae-angliae	New England aster	75 per cent killed; 25 per cent retarded.
novae-angliae roseus	Rosy New England aster	Do.
novae-angliae, var. Mrs. F. Raynor	New England aster	Do.
subcaeruleus	India aster	Normal.
var. Grace Sweet	do	Do.
var. The President	do	Do.
var. White Climax	do	Do.
Astilbe sp.	Astilbe	Do.
Azalea amoena	Amoena azalea	Killed.
indica	Indica azalea	Do.
Baptisia australis	Blue wild-indigo	Normal.
Berberis thunbergi atropurpurea	Red Japanese barberry	Killed.
Bignonia grandiflora	Chinese trumpetcreeper	Normal.
Calimeris incisa	Calimeris	Killed.
Callicarpa purpurea	Chinese beautyberry	Retarded.
Canna indica—		
var. King Humbert	Canna	75 per cent killed; 25 per cent retarded.
var. Mary Milon	do	Do.
var. Mrs. A. F. Conrad	do	Do.
var. Mrs. Antoine Wintzer	do	Do.
Centaurea dealbata	Persian centaurea	Killed.
montana alba	White mountain-bluet	Do.
Centranthus ruber	Jupitersbeard	Do.
Chelone glabra alba	White turtlehead	Do.
lyoni	Pink turtlehead	Do.
Chrysanthemum coccineum	Painted lady	Do.
maximum	Pyrenees chrysanthemum	Do.
Cibotium schiedei	Mexican cibotium	Do.
Clematis heracleaefolia davidiana	Fragrant tube clematis	Do.
Convallaria majalis	Lily-of-the-valley	Do.
Coreopsis lanceolata	Lance coreopsis	Do.
rosea	Rose coreopsis	Do.
Dahlia sp.—		
var. Barbara Snow White	Dahlia	Do.
var. Bob Newcombe	do	Do.
var. Bob Pleuse	do	Do.
var. Cactus	do	Do.
var. Elite Glory	do	Do.

TABLE 12.—*Effect of immersion in water at 112° F. for 70 minutes on dormant plants*—Continued

Name of plant		Condition of the plant after treatment
Scientific name	Common name	
Dahlia—Continued.		
var. Flambuoyant	Dahlia	Normal.
var. Fellowes	do	Do.
var. Geisha	do	Do.
var. Granada	do	Do.
var. Hera	do	Do.
var. His Majesty	do	Do.
var. Jean Chazot	do	Do.
var. Jersey Empress	do	Do.
var. Jersey Sovereign	do	Do.
var. Josephine Mendillo	do	Do.
var. Lemonade	do	Do.
var. Lillian Baldwin	do	Do.
var. Little Beauty	do	Do.
var. Little Jewel	do	Do.
var. L. W. Alton	do	Do.
var. Margaret Woodrow Wilson	do	Do.
var. Marion	do	Do.
var. Midget	do	Do.
var. Mme. Gygax	do	Do.
var. Nagel's Glory	do	Do.
var. Oasis	do	Do.
var. Riverton Golden Glow	do	Do.
var. Rodman Wanamaker	do	Do.
var. Skagerrak	do	Do.
var. Sun Maid	do	Do.
var. Sunny South	do	Do.
var. Tango Century	do	Do.
var. Wapiti	do	Do.
var. Yukon	do	Do.
Dianthus caryophyllus	Clove pink, carnation	Do.
deltoides	Maiden pink	Do.
Dicentra formosa	Western bleedingheart	Do.
Digitalis lanata	Grecian foxglove	Do.
purpurea gloxiniaeflora	Gloxinia foxglove	Do.
Echinops ritro	Steel globethistle	Killed.
Elymus glaucus	Wild-rye	Normal.
Erigeron coulteri	Fleabane	Killed.
Eryngium maritimum	Seaholly	Do.
planum	Eryngo	Do.
Euonymus radicans	Wintercreeper	Normal.
Eupatorium urticaefolium	Snow thoroughwort	50 per cent killed; 50 per cent retarded.
Euphorbia corollata	Flowering spurge	Normal.
Festuca glauca	Blue fescue	Killed.
Filipendula palmata elegans	Siberian meadowsweet	Normal.
ulmaria	European meadowsweet	Do.
Forsythia suspensa	Weeping forsythia	Do.
Franklinia alatamaha	Franklinia	Do.
Gaillardia aristata	Common perennial gaillardia.	Killed.
Geum chiloense	Chiloe avens	Normal.
Gypsophila repens	Creeping gypsophila	Normal (inside).
repens rosea	do	Killed (outside).
Hedera helix	English ivy	Killed.
Helenium hoopesi	Orange sneezeweed	Normal.
Heliopsis helianthoides pitcherinna	Pitcher heliopsis	Do.
Hemerocallis dumortieri	Early daylily	Do.
fulva kwanso	Kwanso daylily	Do.
Hosta caerulea	Blue plantainlily	Do.
Humulus lupulus	Common hop	Do.
Hydrangea arborescens	Smooth hydrangea	Retarded.
(chiefly) *opuloides*	House hydrangea	Killed or retarded.
var. America	do	Do.
var. Avalanche	do	Do.
var. Baby Bimbenet	do	Do.
var. Caprice	do	Do.
var. Coquelicot	do	Do.
var. Domotii	do	Do.
var. Eclaireur	do	Do.
var. E. G. Hill	do	Do.
var. Elmar	do	Do.
var. General de Vibraye	do	Do.
var. La Marne	do	Do.
var. Lancelot	do	Do.
var. Lilie Mouillère	do	Do.
var. Louis Mouillère	do	Do.

TABLE 12.—*Effect of immersion in water at 112° F. for 70 minutes on dormant plants*—Continued

Name of plant		Condition of the plant after treatment
Scientific name	Common name	
Hydrangea (chiefly) *opuloides*—Contd.		
var. Marechal Foch	House hydrangea	Killed or retarded.
var. Mme. Agnes Barillet	do	Do.
var. Mme. Auguste Nonin	do	Do.
var. Mme. Chautard	do	Do.
var. Mme. René Jacquet	do	Do.
var. Otaksa	do	Do.
var. Radiant	do	Do.
var. Splendens	do	Do.
var. Success	do	Do.
var. Suzanne Cayeux	do	Do.
var. William Pfitzer	do	Do.
var. Yvonne Cayeux	do	Do.
Hypericum moserianum	Goldflower	Normal.
Iberis sempervirens	Evergreen candytuft	Do.
Iris cristata	Crested iris	Do.
japonica	Fringed iris	Do.
ochroleuca	Yellowband iris	Retarded.
pallida	Tall bearded iris	Normal.
pseudacorus	Yellowflag iris	Retarded.
sibirica	Siberian iris	Do.
variegata	Tall bearded iris	Do.
Kerria japonica	Kerria	Normal.
Kniphofia uvaria	Common torchlily	Do.
Lialris pycnostachya	Cattail gayfeather	Do.
Limonium latifolium	Bigleaf sea-lavender	Do.
Lonicera japonica halliana	Hall Japanese honeysuckle	{Killed (outside). Normal (inside).
var. *variegata*	Japanese honeysuckle	Killed.
var. Chinese Evergreen	do	Do.
Lychnis chalcedonica	Maltese cross	Normal.
coronaria alba	White rose campion	Do.
Lythrum salicaria roseum	Rose loosestrife	Do.
Malva moschata	Musk mallow	Killed.
Mentha spicata	Spearmint	Normal.
Monarda didyma rosea	Rose beebalm	Do.
Nierembergia rivularis	Whitecup	Do.
Paeonia albiflora,		
var. Edulis Superba	Chinese peony	Do.
officinalis	Common peony	Do.
var. Albert Crousse	do	Do.
var. Avalanche	do	Do.
var. Baroness Schroeder	do	Do.
var. Berlioz	do	Do.
var. Canari	do	Do.
var. Charlemagne	do	Do.
var. Duchesse de Nemours	do	Do.
var. Eugene Verdier	do	Do.
var. Festiva Maxima	do	Do.
var. L'Indispensable	do	Do.
var. Livingstone	do	Do.
var. Louis Van Houtte	do	Do.
var. Marie Jacquin	od	Do.
var. Meissonier	do	Do.
var. Mme. Emile Galle	do	Do.
var. Mlle. Leonie Calot	do	Do.
var. Mons. Jules Elie	do	Do.
var. Sarah Bernhardt	do	Do.
Pentstemon torreyi	Torrey pentstemon	Retarded.
laevigatus digitalis	Foxglove pentstemon	Do.
Phalaris arundinacea variegata	Ribbon grass	Do.
Phlox amoena	Amoena phlox	Normal.
glaberrima suffruticosa	Smooth phlox	Do.
paniculata	Garden phlox	Do.
var. Albion	do	Do.
var. Bacchante	do	Do.
var. Bridesmaid	do	Do.
var. Champs Elysee	do	Do.
var. Jacquiline Maille	do	Do.
var. Jeanne d'Arc	do	Do.
var. La Vague	do	Do.
var. L'Esperance	do	Do.
var. Louise Abbema	do	Do.
var. Mia Ruys	do	Do.
var. Miss Lingard	do	Do.
var. Mrs. Jenkins	do	Do.
var. Rheinlander	do	Do.
var. Rijnstroom	do	Do

TABLE 12.—*Effect of immersion in water at 112° F. for 70 minutes on dormant plants*—Continued

Name of plant		Condition of the plant after treatment
Scientific name	Common name	
Physalis francheti	Lantern groundcherry	Retarded.
Physostegia virginiana	Virginia false-dragonhead	Normal.
Picea pungens	Colorado spruce	Killed.
Polemonium humile	Dwarf polemonium	Retarded.
Polygonum compactum	Fleeceflower	Normal.
Polypodium vulgare	Common polypody	Killed.
Potentilla, var. William Rollinson	Cinquefoil	Normal.
Poterium obtusum	Japanese burnet	Killed.
Rhododendron catawbiense	Catawba rhododendron	Killed.
var. Caractacus	do	Do.
var. Catawbiense	do	Do.
var. Everest	do	Do.
var. John Walter	do	Do.
var. Sir Henry Havelock	do	Do.
Rudbeckia laciniata	Cutleaf coneflower	Do.
maxima	Great coneflower	Do.
subtomentosa	Sweet coneflower	50 per cent killed; 50 per cent retarded.
Saponaria ocymoides splendens	Rock soapwort	Normal.
Scabiosa japonica	Japanese scabiosa	Do.
Sedum spectabile	Showy stonecrop	Normal (inside). Retarded (outside).
Senecio pulcher	Uruguay groundsel	Killed.
Sidalcea candida	White prairiemallow	Do.
Silene schafta	Schafta catchfly	Do.
Silphium perfoliatum	Cup rosinweed	50 per cent killed; 50 per cent retarded.
Solidago altissima	Tall goldenrod	Do.
shorti	Goldenrod	Do.
Spiraea bumalda var. Anthony Waterer	Bumalda spirea	Normal.
prunifolia	Bridalwreath	Do.
Stachys grandiflora	Big betony	Killed.
Statice cephalotes rosea	Thrift	Do.
Stokesia laevis	Stokesia	Do.
Symphoricarpos vulgaris	Coralberry	Normal.
Syringa vulgaris	Common lilac	Normal.
Thalictrum glaucum	Dusty meadowrue	Do.
"*intermedium*"	Meadowrue	Do.
Thuja occidentalis	American arborvitae	Killed.
Thymus serpyllum aureus	Thyme	Retarded.
Tradescantia virginana	Virginia spiderwort	Normal.
Tritonia, var. Westwick	Tritonia	Do.
Trollius sp	Globeflower	Do.
Tunica saxifraga	Saxifrage tunicflower	Do.
Vaccinium sp	Blueberry	Do.
var. Adams	do	Do.
var. Cabot	do	Do.
var. Dunfee	do	Do.
var. Grover	do	Do.
var. Harding	do	Do.
var. Katherine	do	Do.
var. Pioneer	do	Do.
var. Rancocas	do	Do.
var. Rubel	do	Do.
var. Sam	do	Do.
var. 803N	do	Do.
var. 823A	do	Do.
Valeriana officinalis	Common valerian	Do.
Veronica incana	Woolly speedwell	Do.
longifolia subsessilis	Clump speedwell	Do.
repens	Creeping speedwell	Killed.
spicata	Spike speedwell	Normal.
spuria	Bastard speedwell	Do.
Weigela rosea	Pink weigela	Do.

SUMMARY

Experiments were conducted at Moorestown, N. J., to test the possibilities of hot water as a means of destroying the stages of the Japanese beetle in the soil about the roots of plants.

The results of large numbers of tests showed that all stages of the beetle could be killed by immersion in water at temperatures

ranging from 110° to 130° F. In general, the necessary period of treatment varied inversely with the degree of temperature, but some stages were slightly more resistant than others.

Treatment with hot water at 112° F. for 70 minutes was found to be practically exterminative of all stages of the beetle.

A tank was developed in which water in circulation could be maintained at a constant temperature.

Tests were made to determine the time required to cause masses of soil of different sizes and types to become heated throughout to a given temperature.

Laboratory tests indicated that the hot-water treatment was fatal to Azalea, Rhododendron, Picea, Berberis, and Hydrangea, but could be used successfully on Dahlia, Iris, Paeonia, Phlox, Forsythia, Spiraea, Syringa, and Weigela (Diervilla).

The effects of the hot-water treatment on a large number of plants are presented in Table 12.

Recommendations based on the results of experiments reported in this bulletin are given in the section that follows.

RECOMMENDATIONS FOR THE USE OF HOT WATER ON NURSERY PLANTS

With the experimental work just presented as a basis, the following recommendations are made for the treatment of nursery plants with hot water to destroy infestations of the Japanese beetle in the soil about the roots.

Equipment: It is necessary to have a tank of water that is equipped with a suitable heating device, and a system for circulating the water to maintain the temperature uniformly at 112° F. The tank should be of sufficient capacity, and be of such shape as to adequately handle the different types of nursery stock. Equipment for drying certain plants after treatment may be necessary.

Varieties of plants: Experimentally, certain varieties of herbaceous and deciduous plants have been treated successfully with hot water, as may be seen by consulting Table 12; it is therefore expected that these varieties can be treated in a satisfactory manner in the commercial nurseries on a large scale.

Condition of the plants: Plants are usually most resistant to hot water when they are dormant, and most susceptible when they are growing actively. It is therefore recommended that treatment be applied only when the plants are dormant or semidormant.

Temperature: The water must be maintained at a temperature of 112° F. for the entire period of treatment. If the temperature falls below 111.5° F. the infestation may not be destroyed; if it rises above 112.5° F. the plants may be injured.

Period of treatment: The treatment must be continued for 70 minutes after the soil about the roots is heated throughout to 112° F.

Preparation of plants for treatment: A large proportion of the varieties which are treated with hot water have roots which are practically free of all loose soil. All excess soil must be removed, the roots pruned, and large clumps divided as much as possible without injuring the plants. Small plants, bulbs, and rootstocks may be packed loosely in wire baskets, or in other containers, provided water can circulate freely through the masses. Large plants

must be placed individually in the hot water. Before the plants are immersed, thermometers must be inserted into at least three of the largest clumps, baskets, or root masses of each variety, in such a manner that the sensitive part of the thermometer is at the center of each mass, and must be left in place until the end of the treatment.

Application: The roots must be immersed completely. The temperature of the water may drop for a few minutes after the plants are immersed, but it should soon come back to the required degree. A record of the temperature of the masses of plants and of the water must be made every five minutes as long as the plants are in the water. After the masses are heated to 112° F. the temperature must be maintained for 70 minutes.

Care of plants after treatment: The insecticidal action of hot water is practically complete when the plants are removed from the tank. The way plants are handled after treatment may seriously affect subsequent growth. Bulbs and tubers should be dry when packed for shipment. Plants should be cooled slowly to room temperatures. Plants should not be removed from the hot water and heeled in in cold soil. The plants should be potted or set in the ground as soon as possible after cooling to room temperature.

LITERATURE CITED

(1) BARTLETT, O. C.
1927. PLANT INSPECTION AND QUARANTINE LAWS, ORDERS, AND REGULATIONS APPLYING IN THE STATE OF ARIZONA. QUARANTINE ORDER NO. 3. THE GRAPE MEALY BUG—THE GRAPE PHYLLOXERA. Ariz. Comm. Agr. and Hort. [1] p. Phoenix, Ariz.

(2) BROWN, N. A.
1929. TREATING PEONY ROOTS. Florists' Rev. 63 (1625) : 38.

(3) BYARS, L. P.
1921. NOTES ON THE CITRUS-ROOT NEMATODE, TYLENCHULUS SEMIPENETRANS COBB. Phytopathology 11 : 90–94, illus.

(4) ——— and GILBERT, W. W.
1920. SOIL DISINFECTION BY HOT WATER TO CONTROL THE ROOT-KNOT NEMATODE AND PARASITIC SOIL FUNGI. U. S. Dept. Agr. Bul. 818, 14 p., illus.

(5) CALIFORNIA DEPARTMENT OF AGRICULTURE, BUREAU OF PLANT QUARANTINE AND PEST CONTROL.
1926. PEST CONTROL RULING "B." PREVENTION OF SPREAD OF CERTAIN BULB PESTS. 8 p.

(6) DOUCETTE, C. F.
1926. THE EFFECT ON NARCISSUS BULB PESTS OF IMMERSION IN HOT WATER. Jour. Econ. Ent. 19 : 248–251.

(7) FLEMING, W. E., and BAKER, F. E.
1928. HOT WATER AS AN INSECTICIDE FOR THE JAPANESE BEETLE IN THE ROOTS OF NURSERY STOCK. Jour. Econ. Ent. 21 : 818–822.

(8) ——— and BAKER, F. E.
1929. THE HOT-WATER TREAMENT OF NURSERY PLANTS. Jour. Econ. Ent. 22 : 314–317.

(9) GIBSON, G. W.
1926. THE CONTROL OF THE NARCISSUS EELWORM. Jour. Min. Agr. [Gt. Brit.] 33 : 531–544, illus.

(10) HARTZELL, F. Z.
1929. APPLICATION OF ONE OF PEARSON'S PROBABILITY THEOREMS AND SOME SPECIAL PROBABILITY EQUATIONS TO ENTOMOLOGICAL DATA. Jour. Econ. Ent. 22 : 202–209.

(11) JARDINE, W. M.
1926. NARCISSUS-BULB QUARANTINE. NOTICE OF QUARANTINE NO. 62. U. S. Dept. Agr., Fed. Hort. Bd. Serv. and Regulat. Announc. 88 : 70–76.

(12) JEROME, H.
1924. STATISTICAL METHOD. 395 p., illus. New York and London.
(13) LEACH, B. R.
1921. EXPERIMENTS WITH HOT WATER IN THE TREATMENT OF BALLED EARTH ABOUT THE ROOTS OF PLANTS FOR THE CONTROL OF JAPANESE BEETLE LARVAE. Soil Sci. 12 : 63–68, illus.
(14) MARLATT, C. L.
1926. DISINFECTION OF NARCISSUS BULBS. HB–195. U. S. Dept. Agr., Fed. Hort. Bd. Serv. and Regulat. Announc. 87 : 36–39.
(15) MORDVILKO, A. K.
1925. [PHYLLOXERA IN NORTH CAUCASUS (KUBAN PROVINCE AND BLACK SEA COAST). OBSERVATIONS MADE IN 1925. Severo-Kavkazs. Kraev. Stantz. Kashch. Rast. (Northern Caucasian Regional Sta. Plant Protect.) Ser. A, no. 9, 38 p. [In Russian. Abstract in Rev. Appl. Ent. (A) 14 : 195.]
(16) NAUMAN, A.
1926. SCHÄDLINGE AN CHRYSANTHEMUM INDICUM. Kranke Pflanze 3: 185–188.
(17) NOYES, G. H.
1922. SUMMARY OF THE CLIMATOLOGICAL DATA FOR THE UNITED STATES, BY SECTIONS. SECTION 99, THE SOUTHERN INTERIOR AND THE SEA COAST OF NEW JERSEY. U. S. Dept. Agr., Weather Bur. Bul. W, Ed. 2, v. 3, sect. 99.
(18) PATTEN, H. E.
1909. HEAT TRANSFERENCE IN SOILS. U. S. Dept. Agr., Bur. Soils Bul. 59, 54 p., illus.
(19) RAMSBOTTOM, J. K.
1925. THE CONTROL OF THE NARCISSUS EELWORM. Gard. Chron. 77 : 76–77, 96.
(20) SCOTT, C. E.
1924. TYLENCHUS DIPSACI KÜHN ON NARCISSUS. Phytopathology 14: [495]–502, illus.
(21) SMITH, F. F.
1927. PSEUDOCOCCUS MARITIMUS EHRHORN, A PEST OF GLADIOLUS AND CALLA. (Scientific Note) Jour. Econ. Ent. 20 : 843–844.
(22) STEWART, F. H.
1921. THE ANATOMY AND BIOLOGY OF THE PARASITIC APHELENCHI. Parasitology 13 : 160–179, illus.
(23) THOMAS, E. E.
1923. THE CITRUS NEMATODE, TYLENCHULUS SEMIPENETRANS. Calif. Agr. Expt. Sta. Tech. Paper 2, 34 p., illus.
(24) WILCOX, J.
1926. THE LESSER BULB FLY, EUMERUS STRIGATUS FALLEN, IN OREGON. Jour. Econ. Ent. 19 : 762–772, illus.